A Global Overview of Inter-Basin Water Transfer Schemes, with an Appraisal of Their Ecological, Socio-Economic and Socio-Political Implications, and Recommendations for Their Management

by

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EXECUTIVE SUMMARY

Introduction

In many dryland environments (semi-arid, arid and hyper-arid countries), where rainfall is unevenly distributed and unpredictable, inter-basin water transfers (IBTs) are frequently perceived as the most feasible solution to the problems associated with the skewed (in terms of human water demand) distribution of available aquatic resources in relation to human population centres and human needs. In many parts of the world, water transfers have become the life blood of developing and extant human settlements, for which no alternative is currently perceived to be available. The rationale for the development of IBTs varies according to climate and social needs. In countries such as Canada and Norway, which have comparatively high rainfalls, IBTs are primarily used to augment the power generation potential of hydro-electric schemes, while in drier countries, IBTs supply potable and irrigation water.

In international terms, water transfers have begun to assume increasing significance, while significant improvements in engineering have enabled IBTs to become far more important in terms of the volumes transferred and the distances traversed. However, assessments of the effects of IBTs on the aquatic systems and human communities involved are few. Such assessments usually are limited to the planning and construction phases, with no follow-through, post-construction, in order to assess functioning and effects. Ecological concerns surrounding IBTs have been virtually ignored world-wide.

Where ecological and environmental work has been undertaken on proposed IBTs, it is conceptual and empirical by nature, and pre- and post-transfer ecological work has rarely been undertaken. Thus, the recent upswing in the number proposals for IBTs, world-wide, has occurred despite a lack of adequate knowledge of the effects of such schemes. Furthermore, public opposition to transfers has begun to increase due to a growing awareness that water is a finite resource within any catchment, and that the initiation of a transfer out of a donor catchment may result in a permanent loss of water in that catchment, to the detriment of its future development. The benefits and costs of IBTs are rapidly being subjected to critical appraisal, particularly from communities living within the donor catchments.

Aims of the Report

The main aims of the report were to:

- Increase our knowledge concerning the distribution, operation and widely varying effects of inter-basin water transfer schemes (IBTs), at national, international (particularly with Australian and American collaboration), and global levels.

- Develop a synthesis of the literature available on the ecological (physical, chemical and biological), socio-political and socio-economic impacts of IBTs.

Definition of IBTs

Following Davies *et al*. (1992), we have adopted a definition of an inter-basin transfer of water as:

"*...the transfer of water from one geographically distinct river catchment or basin to another, or from one river reach to another*."

This definition encompasses water transfers of all volumes, across any distance both within and between catchments. IBTs comprise a donor (or source) system, a transfer route and recipient system.

Recovery and Reset

It is likely that IBTs represent a disruption of the river continuum, similar to that caused by impoundment, and other forms of river regulation. Consequently, aquatic systems affected by IBTs can be expected to recover some distance from the scheme. In the temporal context, many IBTs cease for some part of the year, especially where the reason for transfer is irrigation. Thus, the rivers involved, if not impounded, will have the opportunity to recover to some extent, before transfer recommences. This recovery will depend on several factors such as the location of the water transfer, the robustness of the systems, the period during which the transfer ceases and the timing of releases. Given that these arguments are well-founded, the application of river ecosystem theory, including the River Continuum Concept (RCC; Vannote *et al*., 1980) and Serial Discontinuity Concept (SDC; Ward & Stanford, 1983) is not only possible, but, coupled with the recovery aspects of the SDC, should have important implications for the design of future IBTs and for the design, operation and management of extant schemes.

Global Review of IBTs and their Ecological Effects

The following section provides a summarised description of IBT schemes across the globe, and the effects (both predicted and observed) of these schemes on the ecological functioning of the aquatic systems involved, in terms of physical, chemical and biological characteristics, and on socio-economic and cultural aspects of human communities.

A. CONTINENTAL AFRICA

Egypt

Jonglei Project (incomplete); transfers water for irrigation within the White Nile Basin; maximum: 4×10^9 m^3 yr^{-1}.

- It is probable that snails, found to be intermediate hosts to trematode parasites causing several diseases in humans and stock, could colonise the margins of the main Jonglei Canal, and secondary, draw-off canals, and could populate the new wetland habitat created by the IBT; and
- Provision of suitable habitat within the Jonglei Canal has increased the spread of the invasive water hyacinth (*Eichhornia crassipes*) and the water cabbage (*Pistia stratiotes*).

Libya

Great Man-made River Project; transfers water from the Alkufrah/Assarir/Fezzan regions to the coastal region, for irrigation; maximum 820×10^9 m^3 yr^{-1}.

Israel

Jordan River Project; from the Jordan River (Sea of Galilee) to the central and southern coastal plain; for irrigation and municipal water supply; maximum 1200 x 10^6 m^3 yr^{-1}.

- Diversion of the Jordan River away from the Dead Sea has resulted in a reduction of surface area of this inland sea by 300 km^2, or 30% of its original area, leaving factories, that extracted potash and other salts from the seawater, stranded several kilometres from the edge of the sea.

Iraq

Tharthar Development Project; transfers between the Tigris and Euphrates rivers; for irrigation; maximum 1100 x 10^6 m^3 yr^{-1}.

- The coastal marshes of the Tigris and Euphrates rivers are threatened by the almost total diversion of the Euphrates and many of its tributaries – the marshes are globally important as wetland bird habitat.

Jordan

Red-Dead Canal (**proposed**); between the Red Sea and Dead Sea; for replenishing the Dead Sea water source.

Lebanon

Proposed transfer from the Litani River to the Jordan River; for general water supply.

South Africa

Usutu-Vaal River Government Water Scheme; transfers water between the Vaal and Usutu rivers; for electric power and general water supply; maximum 500 x 10^6 m^3 yr^{-1}.

Grootdraai Dam Emergency Augmentation Scheme, within the Vaal catchment; for emergency general supply.

Usutu River Government Water Scheme; transfers within the Usutu River catchment; for power station cooling; maximum 103 x 10^6 m^3 yr^{-1}.

Komati River Government Water Scheme; transfers water from the Komati River to the Olifants River catchment; for power station cooling; maximum 131 x 10^6 m^3 yr^{-1}.

Slang River Government Water Scheme; from the Slang River (Buffalo) to Perdewaterspruit and Schulpspruit (Vaal); for power station cooling.

Tugela-Vaal Scheme; transfers from the Tugela River to the Nuwejaarsspruit (Vaal); for general supply; maximum 631 x 10^6 m^3 yr^{-1}.

- It was expected that the freshwater snail hosts for schistosomiasis, *Biomphalaria* sp. (intestinal bilharzia) and *Bulinus* (*Physopsis*) sp. (urinary bilharzia), would be transferred from the Tugela to the Vaal system – this has not occurred due to temperature differences between the two systems.

Caledon-Modder Scheme; from the Caledon to the Modder River; for municipal and industrial supply; maximum 40 x 10^6 m^3 yr^{-1}.

Lesotho Highlands Water Project (Phase 1A); transfers from the Malibamatso River to the Ash/Liebenbergsvlei River (Vaal); for general water supply; maximum 533 x 10^6 m^3 yr^{-1}.

- Substantial reductions and fluctuations in flow are expected in the donor Malibamatso River; decreased channel size of the Malibamatso is likely;
- Erosion, stream-bed armouring, and transport of sediment down river are expected in the Malibamatso (donor) and Ash/Liebenbergsvlei rivers, as a result of settling of sediment in the source reservoir, Katse;
- Reservoir-induced seismic (RIS) activity has been recorded in the Katse Reservoir area since filling commenced;
- Water in the donor Katse Reservoir is expected to be warmer in summer and cooler in winter than water in the recipient Ash River;
- Invertebrate communities in the recipient Ash/Liebenbergsvlei system are expected to be affected by loss of habitat and smothering by filamentous algae that will establish in the sediment-free water transferred from Katse Reservoir;
- Transfer of lentic taxa to recipient river is expected;
- Filter-feeding taxa are expected to proliferate in the recipient system;
- Establishment of pest simuliid (blackflies) species in the recipient system is possible;
- The clarity of the water released from Katse Dam could lead to increased light penetration, which will encourage the growth of various macrophytes, such as filamentous algae, *Potamogeton* spp (pondweed) and *Typha* spp (bulrush);
- It is also possible that the transfer of clear water to the Vaal River will lead to decreased turbidities in the Vaal Reservoir and thus, to increased plant production; and
- Strong objection exists to the anticipated increase in water tariffs in South Africa, and lack of water-demand management strategies which would reduce the tariff increment.

Lesotho Highlands Water Project (further phases); **proposed** transfers from the Matsoku (Malibamatso) and the Senqunyane to the Ash/Liebenbergsvlei River (Vaal); for general supply; maximum 2207 x 10^6 m^3 yr^{-1}.

- A 1 in 20-year flood equivalent is expected in the recipient Ash/Liebenbergsvlei system; inundation of land in the recipient catchments is also anticipated.

Mhlatuze Government Water Scheme; from the Mhlatuze River to Lake Nseze (Mhlatuze catchment); for municipal and industrial supply.

Orange River Project; water transferred from the Orange River to Teebus (Great Fish), and to the Sundays River; for irrigation, maximum 1700 x 10^6 m^3 yr^{-1}.

- Between 500-800% increase in flow in the recipient Great Fish River has occurred converting the recipient from a seasonal to a perennial system;
- Salinities have been reduced in the recipient Great Fish River;
- Significant changes in riverine invertebrate species composition in the recipient Great Fish River have been recorded, with only 33% of taxa common to pre-and post-transfer communities;
- Significant shifts in the dominant dipteran Chironomidae and Simuliidae species, and trichopteran Hydropsychidae have occurred in the recipient system;
- The pest simuliid, *Simulium chutteri*, has out-competed other species, and causes extensive stock damage and losses in the recipient catchment;
- Increases in high-flow-velocity habitats have favoured the establishment of simuliid larvae;
- The transfer of four fish species to the recipient Great Fish River has occurred as a result of the IBT: smallmouth yellowfish, *Barbus aeneus*, the Orange River mudfish, *Labeo capensis*, the sharptooth catfish, *Clarias gariepinus*, and the rock barbel, *Gephyroglanis sclateri*; and
- It is likely that new individuals have been added to recorded populations in the Great Fish River.

Riviersonderend-Berg-Eerste River Government Water Scheme; from the Riviersonderend system to the Berg and Eerste rivers; for general supply; maximum 130 x 10^6 m^3 yr^{-1}.

- A 570-4400% increase in flow in the recipient Berg River has been recorded;
- The transfer of geosmin, a non-toxic cyanobacterial exudate, from the donor reservoir (Theewaterkloof) to the recipient Berg River, has affected the flesh of rainbow trout in a downstream farm;
- Increases in pH, conductivity, total dissolved and suspended solids, sodium, magnesium, potassium and calcium cations, and sulphate and chloride anions, have been recorded in the recipient Berg River;
- Invertebrate communities below the IBT were significantly increased in terms both of numbers of individuals, and lower overall richness and numbers of taxa, in comparison to communities of sites above the IBT;
- An overall loss of sensitive invertebrate taxa in the recipient reaches has been recorded;
- Filter-feeding taxa appear to benefit from the water transfer in recipient reaches; and
- Significant transfers of lentic taxa from the donor impoundment to the recipient river have been recorded.

Mooi-Mgeni Scheme; from the Mooi River (Tugela) to the Mpofana River (Mgeni); for general water supply; maximum 30 x 10^6 m^3 yr^{-1}.

Mooi-Mgeni Scheme; **proposed** increased transfer from the Mooi (Tugela) to the Mpofana (Mgeni); for general supply; maximum 315 x 10^6 m^3 yr^{-1}.

- Some reaches of the recipient Mpofana River are likely to erode further.

Amatole Scheme; transfer from the Toise and Kubusi rivers to the Yellowwoods and Nahoon rivers; for municipal supply; maximum 225 x 10^6 m^3 yr^{-1}.

- Bank and bed erosion occurs in the recipient rivers.

Palmiet River Scheme; from the Palmiet River to the Steenbras River; for general supply; maximum 22 x 10^6 m^3 yr^{-1}.

Palmiet River Scheme; **proposed** transfer from the Palmiet River to the Steenbras River; for general supply; maximum 127 x 10^6 m^3 yr^{-1}.

Mzimkulu-Mkomaas-Illovo Scheme; **proposed** transfer from the Mzimkulu and Mkomaas rivers to the Mgeni and Illovo rivers; for municipal supply; maximum 375 x 10^6 m^3 yr^{-1}.

Sabie River Government Water Scheme; **proposed** transfer from the Marite River to the Sand and Klein Sand rivers; maximum 25 x 10^6 m^3 yr^{-1}.

The Zambezi Aqueduct; **proposed** transfer from the Zambezi River to Botswana and to the Vaal River; for general supply; maximum 4000 x 10^6 m^3 yr^{-1}.

Tugela-Mhlatuze Transfer; **proposed** transfer from the Tugela River to the Mhlatuze River; for general supply.

Western Cape proposals; **proposed** transfers between the Berg, Olifants and Breede rivers; for general supply.

Namibia

Eastern National Water Carrier; from the Swakop and Omatako rivers and the Karstland boreholes to the Windhoek area; maximum 15-20 x 10^6 m^3 yr^{-1}.

- Water table depression has occurred in the Karstveld area;
- The growth of filamentous algae in open canals is likely to cause decreases in water quality; and
- The open canal is a death trap for animals, from a myriad insects to endangered vertebrate species.

Eastern National Water Carrier; **proposed** transfer from the Kavango River to the Omatako River; for general supply; maximum 9.5 x 10^6 m^3 yr^{-1}.

- The transfer of schistosomiasis (bilharzia) from the Kavango River to recipient areas is anticipated.

Botswana

North-South Water Carrier; from the Shashe River to eastern Botswana; for general supply.

B. CONTINENTAL AMERICA

Canada

Long Lake Diversion; transfers water from the Kenogami River to the Aguasabon River; for pulpwood transport and hydro-electric power generation; maximum 1356 x 10^6 m^3 yr^{-1}.

- Rapid erosion has occurred in diversion channels;
- The transfer of sea lamprey was avoided due to the presence of natural barriers and hydro-electric power dams; and
- Increased fish-egg mortality in the recipient systems has occurred due to increased erosion.

Ogoki Diversion; from the Ogoki River to the Little Jackfish River; for hydro-electric power generation; maximum 3563 x 10^6 m^3 yr^{-1}.

- Erosion has been observed in the recipient Little Jackfish River;
- The transfer of sea lamprey was avoided due to the presence of natural barriers and hydro-electric power dams; and
- Increased fish-egg mortality in the recipient systems has occurred due to increased erosion.

Kemano Diversion; transfer from the Nechako River to the Kemano River; for hydro-electric power generation; maximum 3626 x 10^6 m^3 yr^{-1}.

- The Nechako chinook salmon was adversely affected by flow disruptions from the closure of dams, warm-water releases and siltation in the donor Nechako River;
- Increased discharges in the recipient Kemano River have resulted in pink and chum salmon runs;
- No compensation was given for the loss of approximately 350 000 ha of Tweedsmuir Park, a popular tourist destination in Canada;
- Cheslatta Band Indians living in the area to be inundated had to abandon their traditional occupations of hunting, trapping and fishing, and were afforded meagre compensation; and
- The developer met with the indigenous communities only three days before flooding began.

Churchill River Diversion; from the Churchill River to the Rat, Burntwood and Nelson rivers; for hydro-electric power generation; maximum 24 440 x 10^6 m^3 yr^{-1}.

- Changes in flows were as follows - a 35-fold increase in the Rat River and a 7-fold increase in the Burntwood River; a 34% increase was expected in the lower Nelson River;
- A 75% reduction in flow in the donor Churchill River occurred;

- The receiving water body, Southern Indian Lake, suffered depressed water temperatures as a result of the IBT releases; and
- Soils containing mercury leached and led to increased mercury levels in fish, and to reduced whitefish catches.

James Bay Project; transfer from the Eastmain, Caniapiscau and Sakami rivers to the La Grande Rivière; for hydro-electric power generation; maximum 50 457 x 10^6 m^3 yr^{-1}.

- Flows in the donor Eastmain River were reduced by 87% while a second donor, the Caniapiscau River exhibited a 43% flow reduction;
- A 2-fold increase in discharge in the recipient, La Grande Rivière was recorded; and
- Many traditional sites for Indian and European settlements on the river banks have been lost as a result of raised water levels in the recipient La Grande Rivière Basin.

McGregor Diversion; **proposed** transfer from Fraser River to the Peace River; to reduce flooding and for hydro-electric power generation; maximum 6 x 10^6 m^3 yr^{-1}.

- The transfer of fish and their protozoan and metazoan parasites was expected between the Pacific-draining donor Fraser River and the Arctic-draining recipient Peace River;

United States of America

Los Angeles Aqueduct (California); from Owens Lake to the Los Angeles metropolitan area; for general water supply.

- The Owens sucker, *Catostomus fumeiventris*, was transferred to the Los Angeles Basin from the northern donor rivers; and
- A reduction in water levels endangered the donor Mono Lake’s suitability as a nesting and feeding area for migratory waterfowl.

Colorado to Los Angeles (California); transfer from the Colorado River to the Los Angeles metropolitan area; for general supply; maximum 580 x 10^6 m^3 yr^{-1}.

Central Valley Project (California); from the Trinity River to the Sacramento River; for general supply; maximum 3300 x 10^6 m^3 yr^{-1}.

California State Water Project (California); from the Sacramento and Feather rivers to Southern California; for general supply; maximum 5210 x 10^6 m^3 yr^{-1}.

- Decreased numbers of the introduced striped bass, *Morone saxatilis*, the threatened delta smelt, *Hypomesus transpacificus*, and the endangered winter-run chinook salmon, *Onchorynchus tshawytscha* were recorded;
- Spring-run chinook salmon have also declined significantly, perhaps due to IBT-related flow fluctuations;
- Some of the algal species occurring in Silverwood Lake appear to have been transported from the north through the California Aqueduct;
- Reductions in freshwater flows to the San Franscisco Bay have resulted in a 30% reduction in numbers of chinook salmon, *Oncorhyncus tshawytscha*, and an 80% reduction in numbers of striped bass, *Morone saxatilis*;
- The economic impact of these fisheries losses was estimated to be about US $1.3 billion;
- The transfer led to the damming of the scenic Feather River; and
- It is possible that further impoundment of the sensitive Klammath, Trinity and Eel river systems, for southward diversion, in order to maintain the San Francisco Bay Delta, may yet occur.

Truckee Canal (Nevada); transfer from the Truckee River to the Carson River; for irrigation.

Big Thompson Project (Colorado); from the Colorado River to the Platte system; for irrigation and municipal supply; maximum 370 x 10^6 m^3 yr^{-1}.

Frying Pan-Arkansas Project (Colorado); from the Colorado River to the Arkansas River; for irrigation.

Central Arizona Project (Arizona); transfer from the Colorado River to the Gila River; for irrigation; maximum 2650 x 10^6 m^3 yr^{-1}.

San Juan-Chama Transfer (New Mexico); from the Colorado River to the Rio Grande; for irrigation and general supply.

- The diversion from the donor San Juan River has threatened water availability at important American Indian religious sites; and
- Reduced water availability to the communal Hispanic irrigation ditches has threatened the existence of these communities, and has imposed a system of individual water-use priorities on a tradition of communal sharing of surpluses and shortages.

Canadian River Project (Texas); from the Canadian River to the Red, Brazos and Colorado rivers; for municipal and industrial use; maximum 190 x 10^6 m^3 yr^{-1}.

Lake Texoma-Lake Lavon Transfer (Texas/Oklahoma); from the Red River to the Trinity River; supply to Dallas.

- Increased conductivity in the recipient Sister Grove Creek has been reported;
- Substantial reductions in meiofaunal populations on fine sediment and woody substrata have been observed;
- Changes in the abundance of individual fish species have been recorded in the recipient Sister Grove Creek;
- Quantitative and qualitative changes in species composition of the fish assemblages were substantial at some sites in the recipient river system;
- The abundance of two minnows increased, whilst the abundance of one centrarchid species decreased, in the recipient Sister Grove Creek; and
- The potential for a decline in the recreationally-important sport fisheries of Lake Texoma, valued at about US $57 million yr^{-1} in total business sales, US $23 million in personal income, and 718 jobs has been noted.

New York supply (New York); from the Delaware River to New York City; for municipal supply.

Virginia Beach supply (Virginia); transfer from the Roanoke River to the Virginia coast; for municipal supply; maximum 83 x 10^6 m^3 yr^{-1}.

Santee-Cooper Project (South Carolina); from the Santee River to the Cooper River; for hydro-electric power.

- Increased sediment loads in the Cooper River have led to decreased navigational capacities, and to increased ship-channel and harbour maintenance costs; and
- The estuary at the mouth of the Cooper River has changed from a vertically well-mixed estuary to one that is stratified.

Santee-Cooper Re-diversion Project (South Carolina); from the Cooper River to the Santee River; for dilution of sediment in the recipient.

Texas Water Plan (Texas); **proposed** transfer from the Mississippi, Arkansas and White rivers to the Texas High Plains; for irrigation.

- The release of large quantities of water could lead to the proliferation of the encephalitis-carrying mosquitoes.

United States/Canada

North American Water and Power Alliance (N.A.W.A.P.A.); **proposed** transfer from various rivers in Canada and the U.S.A. to rivers in the U.S.A. and Mexico; multi-purpose; maximum 136 000 x 10^6 m^3 yr^{-1}.

- The donor waters are considerably cooler than the recipient waters;
- The migration routes of Caribou would be blocked by IBT canals and dams; and
- Many of Canada's transcontinental transport links would be cut by the proposed reservoirs.

Garrison Diversion Project; **proposed** transfer from the Missouri River in the U.S.A. to various recipients, including Lake Winnipeg, Canada; multi-purpose.

- Missouri River species are expected to establish in new habitat made available in Canada by the IBT, including the shovelnose sturgeon, *Scaphirhynchus platorynchus*, the paddlefish, *Polyodon spathula*, the shortnose gar, *Lepisosteus platostomus*, gizzard shad, *Dorosoma cepedianum*, rainbow smelt, *Osmerus mordax*, river carpsucker, *Carpiodes carpio*, smallmouth buffalo, *Ictiobus bubalus*, Utah chub, *Gila atraria*, and the endangered pallid sturgeon, *Scaphirhynchus albus*; and
- Existing populations of walleye, *Stizostedion vitreum*, sauger, *S. canadense*, and lake whitefish, *Coregonus clupeaformis* in lakes Manitoba and Winnipeg are expected to decline.

Grand Replenishment and Northern Development Canal; **proposed** transfer from the James Bay Basin to the Great Lakes of Canada; for hydro-electric power and flood control.

Mexico

National Water Plan; groundwater in the Lerma Basin, and water from the Cutzamala and Amacuzac rivers transferred to Mexico City; for municipal supply; maximum 1700 x 10^6 m^3 yr^{-1}.

- Land subsidence and drying up of lakes has occurred.

Water Plan for the Noroeste Region; from rivers of Sinaloa State to the Alamos River; multi-purpose.

National Water Plan; **proposed** transfer from the Tecolutla and Oriental rivers to Mexico City; for municipal supply.

Brazil

Transfer from the Paraíba River to the Piraí and Lajes rivers; for hydro-electric power generation; maximum 5045 x 10^6 m^3 yr^{-1}.

Peru

Lima water supply; from the Mantaro River to the Rimac River; for hydro-electric power generation and municipal supply; maximum 1100 x 10^6 m^3 yr^{-1}.

C. CONTINENTAL ASIA

Russia

North Crimean Canal; transfer from the Dnieper River to various recipients; for irrigation.

Kara Kum Canal; from the Amudar'ya to various recipients.

Severskiy Donets-Donbas Canal

- The growth of filamentous algae in open canals has caused deterioration in water quality.

Kazakhstan

Irtysh-Karaganda Canal; from the Irtysh to the Karaganda River; for industry and irrigation.

Russia/Kazakhstan

Siberia-Central Asia Project; **proposed** transfer between the Ob River and the Syrdar'ya, Amudar'ya and Yenisey rivers; maximum 60 000 x 10^6 m^3 yr^{-1}.

- Flow fluctuations are anticipated - between 9 and15% reduction in wet years and between 19 and 31% for dry years in the Ob River; flow reductions are also expected in the Irtysch;
- Reduced inundation of important floodplains is expected;
- Conditions in the seriously impacted recipient, the Aral Sea, are expected to improve;
- Leakage of water from the transport-route canals is likely and may raise groundwater levels;
- Increased conductivity of the Aral Sea is anticipated;
- The potential for the transfer of water-borne diseases and parasites along open canals has been recognised;
- A combination of potential loss of feeding, breeding and wintering areas, pollution, and altered hydrological regimes, could lead to a reduction of between 14 and 17% in commercially-exploited fish catches for the first phase alone; and
- Reductions in commercially-exploited marsh-bird populations are expected in donor areas.

European Transfer Project; **proposed** transfer from the Sukhona and Pechora rivers to the Volga; for irrigation and general supply; maximum 9800 x 10^6 m^3 yr^{-1}.

- PHASE I: Reduced flows are anticipated - 53% reduction in flow in the donor Onega River, and a 43% reduction in Upper Sukhona River; and
- Sedimentation and tributary down cutting are likely in the donor systems.

- PHASE II: Reduced flows are anticipated in the Svir and Neva rivers.

- FURTHER PHASE: Reduced flows of between 40 and 76% are expected in the Pechora River, with concomitant effects on bank stability, navigation and on floodplain ecology.

- OVERALL: Increased freshwater inputs to the Caspian Sea, to the Sea of Azov, to the Volga-Akhtuba floodplain and to the Volga estuary are anticipated;
- Increased concentrations of pollutants are expected in the donor Onega and Sukhona rivers, together with associated increases in pollutants in the Gulf of Finland, due to the diversion of flow from the Neva River;
- The transfer of the intermediate parasite hosts *Bithynia leachii* (a freshwater snail) and *Cyclops* sp. (a crustacean) to southern regions is expected where, at present, these invertebrates are almost absent. These invertebrates are the carriers of opisthorchiasis (liver-fluke disease) and diphyllobothriasis (Broad Fish tapeworm);

- An anticipated increase in water supply to the midland regions is also likely to encourage the establishment of water fever in recipient areas;
- A projected 50% reduction in salmon catches due to the proposed third-stage diversion of water from the Pechora River to the Volga River has been forecast;
- In the proposed recipient, the Aral Sea, past diversions have led to an 80% drop in the catches of bream, carp, zander and vobla. Some 80% of the fish presently caught are the less economically viable sprats; the transfer may alleviate this;
- An anticipated 43% reduction in flow in the donor Upper Sukhona River would have resulted in difficulties for navigation and for timber rafting on the river; and
- Historically significant sites such as the Ferapontovo and Kirrilov-Belozerro monasteries, the Sophia Cathedral, and the settlements of Vologda, Kargopol', Beloozersk and Tot'ma, are felt by some to be threatened by a likely rise in groundwater levels, and consequent flooding, caused by the transfer.

Danube-Dnieper Water Resources Utilisation System; **proposed** transfer from the Danube to Southern Ukraine; for general supply.

Japan

Shin-Nippon Seitetsu Kabushiki Kaisha Scheme; from the Onga River to an iron-manufacturing plant; for industry; maximum 7 x 10^6 m^3 yr^{-1}.

Kagawa Irrigation Project; from the Yoshino River to irrigated lands; for irrigation.

Tama River water supply system; transfers between the Tama, Edo, Sagami and Tone rivers; for municipal supply to Tokyo City; maximum 1000 x 10^6 m^3 yr^{-1}.

Sakawa to Sagami; transfer from the Sakawa River to the Sagami River; for municipal supply.

China

Transfers from the Yangtze River to the Yi-Shu-Si River; multi-purpose:-

South to North Water Project; proposed

Western Route; transfer from the Yangtze River to the Qaidam and Huang rivers and to Dingxi County; for general supply.

Middle Route; f**rom** the Yangtze River to Beijing District and the Han Jiang; for general supply.

East Route; from the Yangtze, Yellow and Huai rivers to Dawen and the North China Plain; for general supply; maximum 30 000 x 10^6 m^3 yr^{-1}.

- Anticipated leakage of water from canals is likely to raise groundwater levels;
- Salinisation of recipient soils is expected;
- The possibility of the transfer of pollutants from donor to recipient catchments is likely;
- Siltation in the lower reaches of the donor Yangtze River is expected to have detrimental effects on the Yangtze estuary, while estuarine- and brackish-water fish could also negatively be affected;

- It is feared that productivity in shallow lakes to be used along transfer route, which serve as important freshwater fisheries and which are also rich growing areas for various economically important plant species, will be reduced as a result of high water levels;
- Anticipated altered flows, sediment transport and tidal gradients in the donor (Yangtze) estuary will adversely affect navigation in these parts of the river and estuary; and
- The are fears that a substantial reduction in the freshwater supplies for the industrial, agricultural and domestic requirements of Shanghai Municipality will occur.

India

Godavari-Krishna-Pennar Link; from the Godavari River to the Krishna River, and from the Krishna River to the Pennar River; for irrigation.

Narmada High-level Canal; **proposed** water transfer from the Narmada River to the Gujarat Region; general supply; maximum 34 690 x 10^6 m^3 yr^{-1}.

Brahmaputra-Ganga Link; **proposed** transfer from the Brahmaputra River to the Ganga (Ganges) River; for flood control and general supply.

Sri Lanka

Mahaweli-Ganga Project; from the Mahaweli River to the Ganga River; for irrigation.

D. AUSTRALASIA

Australia

Snowy Mountains Scheme; transfers between the Murrumbidgee, Eucumbene, Tumut, Murray and Snowy rivers; for hydro-electric power generation; maximum 1130 x 10^6 m^3 yr^{-1} (Phase 1).

- Flow fluctuations in recipient Murray River catchment have occurred together with reductions in flow of between 45 and 99% in the donor Snowy River;
- Water in the Snowy River is 6°C cooler than recipient Murray River water;
- Aquatic insects are likely to have been affected by the accumulation of fine sediments on the Snowy River bed;
- Flow reductions in the Snowy River are leading to a progressive upstream movement of the salt wedge in the lower reaches of the river; and
- A 99% reduction in suspended-sediment yields below the IBT is likely to have effects on deposition and erosion at the river mouth.

Lower River Murray transfers; from the Murray River to eight catchments in the Adelaide/Whyalla region; for municipal supply; maximum 157 x 10^6 m^3 yr^{-1}.

- Increased salinity and turbidity in all recipient reservoirs in Adelaide/Whyalla area has occurred; and
- Water transfers from the Murray River have elevated nutrient levels in recipient reservoirs in the Adelaide/Whyalla area, leading to increases in blooms of toxic cyanobacteria.

Nymboida River-Blaxlands Creek Scheme; transfer from Nymboida River (a tributary of the Clarence River) to Goolang and Blaxland creeks; for hydro-electric power.

- Erosion of channels in recipient Blaxland Creek has been reported; and
- River rehabilitation measures have cost A$ 0.5 million.

Shoalhaven-Wingecarribee; from the Shoalhaven River to the Wingecarribee River; for municipal supply; maximum 1000 x 10^6 m^3 yr^{-1}.

- Inundation of land has occurred in places; bank and bed erosion are common; over-bank or in-channel sedimentation is reported in places.

Barnard-Hunter; from the Barnard River to the Hunter River; for hydro-electric power generation; maximum 20 x 10^6 m^3 yr^{-1}.

New Zealand

Waitaki Power Scheme; from Lake Tekapo (in the Waitaki Basin) to Lake Pukaki (also in the Waitaki Basin); for hydro-electric power generation, irrigation and flood control; maximum 2340 x 10^6 m^3 yr^{-1}.

Rangitata Diversion Race; from the Rangitata and Ashburton rivers to the Rakaia River (winter), and to the Hinds and Ashburton rivers, and coastal, spring-fed creeks (irrigation season); for hydro-electric power generation (winter) and irrigation (summer); maximum 730 x 10^6 m^3 yr^{-1}.

Tongariro Power Scheme; from the Wanganui, Rangitaiki and Whangaehu river tributaries to the Waikato River; for hydro-electric power generation; maximum 1000 x 10^6 m^3 yr^{-1}.

Managahao Power Scheme; transfer from the Mangahao River (Manawatu Basin) to the Tokomaru River (Manawatu Basin); for hydro-electric power generation; maximum 160 x 10^6 m^3 yr^{-1}.

Manapouri Power Scheme; from the Waiau River to the sea in the Doubtfull Sound; for hydro-electric power generation; maximum 10 000 x 10^6 m^3 yr^{-1}.

E. EUROPE

Norway

Glåma-Rena Transfer; transfer from the Glåma River to the Rena River; for hydro-electric power generation.

- Densities of Trichoptera, Ephemeroptera and Plecoptera have become considerably lower below the donor impoundment.

Veo-Smådøla Transfer; transfer from the River Veo to the Smådøla River; for hydro-electric power generation.

- Reduced recruitment and availability of important food organisms has resulted in reduced numbers of introduced brown trout, *Salmo trutta*, in the recipient Smådøla River**.**

Aurland Hydropower Scheme; within the Aurland River catchment; for hydro-electric power generation.

Ulla-Førre hydro-electric power scheme; from the Suldalslågen River to the Hylsfjorden system; for hydro-electric power generation; maximum 410 x 10^6 m^3 yr^{-1}.

- The possibility exists that returning migratory salmon will enter the Hylsfjorden River rather than the Suldalslågen River, as a result of the transfer of population-specific pheromones to Hylsfjorden system from the donor system.

United Kingdom

Kielder Water Scheme; from the River Tyne to the Wear and Tees rivers; for hydro-electric power generation and compensation releases; maximum 200 x 10^6 m^3 yr^{-1}.

- The flow in the River Wear was doubled, while water velocities increased tenfold in some areas of the channel;
- Dilution of pollutants is possible in the recipient basins;
- Flow changes are expected to lead to shifts in fish spawning grounds;
- Live mayfly (Ephemeroptera) and chironomid (Diptera) taxa have been transferred to the River Wear, as well as dead and fragmented cladocerans (crustacean zooplankton);
- Populations of diatoms in the recipient reservoirs owe their persistence to re-inoculation from IBTs; and
- Disjunct distributions of some macrophyte species in the donor Tyne River, and the recipient Wear and Tees rivers could be mixed as a result of the IBT.

Ely Ouse to Essex Scheme; transfer from the Ely Ouse River to the Stour, Colne and Blackwater rivers; maximum 180 x 10^6 m^3 yr^{-1}.

- Transfers of pesticide residues have taken place from the Ely Ouse catchment to the Essex catchment where, tomatoes produced in the Essex system, were ultimately rendered unmarketable as the result of the transfer of contaminants;
- Transfer of beet factory effluent from the Ely Ouse River to the Essex River has been recorded;
- The dilution of a sewage spill in a recipient, the River Stour was achieved using water from the donor via the IBT;
- Screening and chlorination of Ely Ouse River water is now necessary to prevent the spread of the alien zebra mussel, *Dreissena polymorpha*, and diatom blooms;
- The transfer of the predatory fish, *Stizostedion lucioperca*, appears to have occurred, from the Ely Ouse River to the recipient River Stour;
- Reduced nesting successes of birds in headwater regions of the River Stour have been recorded. This reduction is due to temporary drying up of the river during shuts-down;
- Transfers of *Stephanodiscus* blooms between the catchments led to public complaints about potable water quality; and
- Shifts in algal dominance have occurred, from a *Melosira* sp.-dominated system, to one dominated by *Stephanodiscus*.

Severn-Thames Transfer; **proposed** transfer from the River Severn to the River Thames; for general supply; maximum 140 x 10^6 m^3 yr^{-1}.

Severn-Trent Transfer; **proposed** transfer from the River Severn to the River Trent; for general supply; maximum 100 x 10^6 m^3 yr^{-1}.

- The establishment of new populations as a result of increased base flows in the recipient Tame River (a tributary of the Trent) is of concern; and
- Reduced numbers of fish in the River Severn are anticipated as a result of the creation of barriers to migration.

Wye-Thames Transfer; **proposed** transfer from the River Wye to the River Thames, via the River Severn; for general water supply; maximum 140 x 10^6 m^3 yr^{-1}.

Slovakia/Hungary

Danube Diversion; transfer within the Danube River catchment; for navigation; maximum 158 000 x 10^6 m^3 yr^{-1}.

Germany

Danube-Main Scheme; from the River Danube to the Main River (Rhine River basin); maximum 3000 x 10^6 m^3 yr^{-1}.

Greece

Acheloos Diversion; from the Acheloos River to the Plains of Thessaly; for irrigation.

France

Eaux de la Neste et de la Garonne; transfer from the Garonne River to the Le Gave de Pau River (tributary of the Adour River); for hydro-electric power generation.

Eaux du Basin Artois Picardie; transfer from the Escaut and Canche rivers to the Lys River; for municipal supply.

Eaux de la Durance et du Verdon; from the Durance River (Rhone River basin) to the Marseilles/Toulon area; for industry and municipal supply.

Spain

Tajo-Segura Transfer; transfer from the Tajo River to the Segura River; for general supply; maximum 350 x 10^6 m^3 yr^{-1}.

- The gudgeon, *Gobio gobio*, has been introduced into the Segura River from the donor Tajo River.

Recommendations for IBT Planning and Management

A list of recommendations for the planning and management of IBT schemes is presented. They have been compiled from the literature, and are not listed in any order of priority. More detailed recommendations are presented in a final research report to the Water Research Commission (Snaddon and Davies, 2000).

- It is clear from the literature that the ecological consequences of inter-basin water transfers are such that great caution is warranted. Data are scarce, but the “precautionary principle” (Department of Environmental Affairs and Tourism, Environmental Policy Discussion Document, 1996) needs to be applied to water-resources planning, allowing for the gathering of data before the feasibility stage of any IBT project. The collection of timely, objective and detailed information on the actual and potential effects of transfers is necessary, in order that all human communities affected by any scheme may assess the IBT in an informed and reasonable manner.

- In addition to the collection of information before the construction of an IBT scheme, all projects should be monitored, in order that the assessment of the effects of IBT can continue through the operational phases (e.g. Davies *et al*., 1992).

- Extant schemes should be re-assessed in terms of their effects, so that detrimental impacts can be minimised through mitigation.

- The environmental aspects of IBTs should not be seen as subordinate to the technical and economic consequences.

- The needs (environmental, social and economic) of all basins concerned in any IBT must be given equal weighting, and must be assessed to the same level for each basin.

- Greater public participation is required during the planning of IBTs, supported by appropriate legislation, and designed to ensure adequate consultation in both the donor and recipient catchments, and communities along the transfer route(s) (e.g. Ortalano, 1978). This has bearing on the environmental consequences of IBTs, as social and environmental issues are intimately linked. Again, the institutional framework for the effective management of this type of participation is crucial to the process. There are examples where public participation is limited to conflict resolution and/or mediation (e.g. Cox *et al*., 1985), but, in most instances, true consultation is favoured (e.g. Platt, 1995). The funding for such participation should usually be provided by the developer (e.g. in Lesotho, the Lesotho Highlands Development Authority; in South Africa, Department of Water Affairs and Forestry).

- The decision to transfer water should not be made by engineers, or water-resource managers alone. If a comprehensive and inclusive consultation process were followed, the decision would be reached over time, with the responsibility for determining the optimal solution spread throughout the communities to be affected by the scheme. This would avoid the situation where distant individuals make decisions for local communities, rather then allowing them that power.

- The land-use implications of IBTs, such as effects on soils, water logging and groundwater levels can be severe and thus, the regulation and management of land-use should be integrated into IBT planning.

- Monitoring the water quality in transfer structures during periods when an IBT is not active, is important. Equally important is the prevention of stagnant water flushing into recipient rivers.

- The transfer and mixing of previously isolated biota between catchments, and thus the mixing of genetic material and the transfer of exotic and invasive fauna and flora, disease vectors and pests of economic importance, are likely consequences of IBTs. There are examples in the literature of all of these threats (Chapters 3 and 4). This requires great caution and extensive investigation during the assessment of the feasibility of such schemes. Once again, the availability of pre-transfer information from donor and recipient catchments would aid in the assessment of the likelihood of the transfer of fauna and flora.

- Similarly, the likelihood of the transfer of water quality problems, such as cyanobacterial blooms, between catchments, should be assessed. The threat of such transfers could be reduced through flexibility in the operational criteria of an IBT scheme, thus allowing for a cease in transfer during periods of risk.

- A botanical investigation to predict the change in vegetative cover under various release strategies would be useful for IBT planning and management. A more definitive prediction of geomorphological response relies on an improved understanding of the effects of various durations of inundation on those species of trees, shrubs and grass prevalent in the riparian zone of a river.

- The results of work in South Africa indicate that the ecological effects of an IBT from a donor impoundment to a river, are similar to those occurring downstream of an impoundment (Snaddon, 1998). Hence, the recommendation is made that such IBT schemes be assessed using methodologies similar to those utilised in the assessment of river impoundment. For example, methodologies developed for the determination of instream flow requirements (IFR) of rivers (e.g. King & Tharme, 1994; King *et al.*, 1995) should be applied to cases where water is transferred into a catchment.

LIST OF ACRONYMS

CAP	Central Arizona Project
CSWP	California State Water Project
ENWC	Eastern National Water Carrier
ETP	European Transfer Project
IBT	Inter-basin water transfer scheme
IFR	Instream flow requirements
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NAWAPA	North American Water and Power Alliance
ORP	Orange River Project
PLHINO	Water Plan for the Noroeste Region, Mexico
RBEGS	Riviersonderend-Berg-Eerste River Government Water Scheme
RCC	River Continuum Concept (*vide*: Vannote *et al*., 1980)
SCAP	Siberia-Central Asia Project
SDC	Serial Discontinuity Concept (*vide*: Ward and Stanford, 1983)
SNWP	South-to-North Water Project (China)
TWS	Texas Water System

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3.1 A summary of some of the biological effects of an IBT from an impoundment on the middle reaches of a donor river, to the upper reaches of a recipient. Thermometer symbols represent changes in temperature, which is cooler in the headwaters, and warmer in the impoundment and downstream of the IBT outlet. P:R is the production:respiration ratio, and the invertebrates drawn in the circles represent the functional feeding groups that are expected to dominate in these systems. CPOM = coarse particulate organic matter; FPOM = fine particulate organic matter.

1. INTRODUCTION

1.1 Introduction

In many semi-arid, arid and hyper-arid countries (for our purposes, we will collectively refer to this mix of climatic types as 'drylands' (see for instance, Davies *et al*., 1993b)), where rainfall is unevenly distributed and unpredictable, inter-basin water transfers (IBTs) are frequently perceived as the only feasible solutions to the problems associated with the skewed (in terms of human water demand) distribution of available aquatic resources in relation to human population centres and human needs. For the purposes of this review, IBTs involve the mass transfer of water from one geographically distinct watershed to another (but see below, section 1.3, for a detailed appraisal of the derivation of this definition and broader definitions of IBTs). Such approaches have, more often than not, developed in response to growing population-, industrial- and agricultural-water demands, mainly in areas where such demands exceed supply. This attitude is especially prevalent in rapidly developing areas such as South Africa (Department of Water Affairs, 1986a), as well as in more developed dryland regions of the planet, such as in the mid- and south-western United States and in Australia. In many parts of the world, water transfers have become the lifeblood of developing and extant human settlements, for which no alternative is currently perceived to be available.

The rationale for the development of IBTs differs from country to country. In many 'First-World' countries (for definition, see Wishart and Davies, 1998), such as Canada and Norway, which have comparatively high rainfalls, IBTs are primarily used to augment the power generation potential of hydro-electric schemes. For example, more than two thirds of the volume of water transferred in Canada (10 000 x 10^6 m^3 yr^{-1}: total Canadian transfers comprise almost 14 000 x 10^6 m^3 yr^{-1} (Golubev and Biswas, 1985)) feeds three large hydro-electric schemes. In international terms, water transfers have begun to assume increasing significance (e.g. Golubev and Biswas, 1985; Petitjean and Davies, 1988a,b; Davies *et al*., 1992). For instance, in the former USSR, a proposal planned to take Northern Siberian rivers south, amounted to between 50 and 60 x 10^6 m^3 yr^{-1} (Voropaev and Velikanov, 1985). In the People's Republic of China, a proposed south-north water transfer could involve a 'Middle Route' transferring some 23 700 x 10^6 m^3 yr^{-1}, and an 'East Route' with a maximum of 30 000 x 10^6 m^3 yr^{-1} (Changming *et al*., 1985). As existing water resources of developed catchments have become fully allocated, only two solutions to the ever-increasing demands for water are perceived to be viable - nearly always avoiding the more efficient use of water through implementation of water-demand management strategies and/or desalination. They are:

- water re-use, and/or
- water transfer from neighbouring river basins.

Additionally, significant improvements in engineering have enabled IBTs to become far more important in terms of the volumes transferred and the distances traversed.

Although some IBTs have been technically assessed, such assessments usually are limited to the planning and construction phases, with no follow-through, post-construction, in order to assess functioning and effects, let alone the ecological implications and effects of such schemes. Indeed, ecological concerns surrounding IBTs have been virtually ignored world-wide. Although one or two "Soviet" and South African projects have received cursory environmental considerations, even here, ecological consequences have been underplayed and, worse, ecological considerations usually assume significance only as mitigation measures when problems arise.

There is a wealth of literature associated with the impacts of abstraction, impoundments, and other forms of river regulation (see for instance review in Davies *et al*. (1993a) and Davies and Day (1998)). Much of the ecological and environmental work undertaken on proposed IBTs, however, is conceptual and empirical by nature, and pre- and post-transfer ecological work has rarely been undertaken. Thus, the recent upswing in the number proposals for IBTs, world-wide, has occurred despite a lack of adequate knowledge of the effects of such schemes. Frequently, only the direct costs of water transport are considered by planners and politicians, while present and possible future losses to donor catchments are rarely evaluated. By the same token, the implications of *increased* flow volumes for recipient catchments are also frequently ignored. The over-riding perception, and often an incorrect one in social and ecological terms, is that the recipient will benefit from an IBT. Furthermore, alternatives to IBTs, such as water-demand management, education of the public into the wiser use of water as a limited and limiting resource, desalination, recycling, realistic pricing, sliding tariffs for excessive use, and so on, are more often than not completely ignored, since ‘hard’-engineering options (requiring strict planning and construction) provide ready statistics for the calculation of the perceived benefits to the recipient catchment. Conversely, the perceived corollary that the variety of ‘softer’ options, such as water re-use and improved irrigation efficiency, is comparatively difficult to assess and quantify. Accordingly, they tend to be avoided. So often, the evaluation of the costs of water development projects in general is measured purely in economic terms with no consideration for human social and environmental medium- and long-term costs (e.g. Reisner, 1986; Davies and Day, 1986, 1998) and, as a result, any so-called ‘cost-benefit analyses’ are flawed from the outset.

Public opposition to transfers has begun to increase due to a growing awareness that water is a finite resource within any catchment, and that the initiation of a transfer out of a donor catchment may result in a permanent loss of water in that catchment, to the detriment of its future development. Legal and political aspects of IBTs are, therefore, becoming complicated, with all parties attempting to protect their future interests in the resource (e.g. Biswas, 1981). Indeed, at the National Water Conservation Campaign Conference at Kempton Park near Johannesburg (October 2-3, 1995), officials of the World Bank issued a clear warning that IBTs, or plans for them, could act as a spark for human conflict in southern Africa. Indeed, there are several examples of such conflicts already between and within countries elsewhere in the world; these are noted later. Thus, the benefits of IBTs are rapidly being subjected to critical appraisal, particularly from communities living within the donor catchments.

This synthesis report provides a review of the literature dealing with IBTs, and particularly, how these schemes affect freshwater ecosystems. An attempt has been made to gather and review information from all over the globe but, inevitably, there are some biases in this report. Firstly, due to the research emphases of the authors, and those of the contributors to this report, more detail has been given for IBTs located in southern Africa, the United States of America, and Australia. Secondly, information is lacking for some regions of the world, and is scant for others. The review of the ecological effects of IBTs is an ongoing project and it is envisaged that new information will be reported elsewhere. The authors of this report would welcome contributions of information from readers of this review.

1.2 Brief Historical Account of Water Development and Inter-basin Water Transfers

The historian Karl Wittfogel has argued that modern society has developed from the desire and need to control rivers (Pearce, 1992). He has referred to early civilisations as ‘hydraulic civilisations’, which developed as a result of the need to centralise the labour force required to build and to manage water schemes. Historically, climatic limitations usually led to the development of water resources, with the main driving force behind the construction of early water-development schemes being the provision of water to irrigate the crops and, later, the development of structures to prevent flooding of those crops, and human settlements (Teclaff and Teclaff, 1973). The first stages of the history of water supply and management occurred in countries with very limited supplies of water, such as Mesopotamia, Egypt and Israel in the Middle East (Pearce, 1992). Further east, in China, pronounced variability in rainfall necessitated the storage of water in order to ensure water supply during dry months.

For thousands of years, the diversion of water has been, and still is, achieved using canals and gravity. One of the first cities to be built in the Middle East was Jericho in present-day Israel. It was sited next to a spring that, to this day, produces 0.076 $m^3 s^{-1}$ (2 x 10^6 $m^3 yr^{-1}$), and from which water was carried along the first recorded irrigation canals, which date back to around 9000 years before present (BP) (Teclaff and Teclaff, 1973). The irrigation ditches were built on the west bank of the River Jordan, and were designed to transport the water to the fields of the desert oasis of Jericho. The availability and efficient distribution of this water allowed the cultivation of locally occurring plants such as peas, beans, emmer and einkhorn; these last two are the predecessors of modern-day wheat. Later, approximately 6000 BP, the transfer of irrigation water led to the establishment of olive and fig orchards and vineyards around Jericho, and from here these crops spread to Asia, North Africa, Greece, Spain, and then to northern Europe.

In the hills of present-day Israel, there is evidence of another form of water diversion that was utilised in the past: the early Palestinians used tunnels. These extended horizontally up to 200 m into the hills where they tapped the water from hidden springs, and led it to storage reservoirs for the irrigation of hill terraces. These tunnels date back to at least 2 000 BP, and may have been built by the Romans, or later by Arabs. Today, the

Israelis do not utilise this ancient system and ironically, as their tractors cannot reach many of the hill terraces, these are left uncultivated.

The history of ancient Mesopotamia, between the Tigris and Euphrates rivers, was determined almost entirely by the availability and quality of water in the region (Teclaff and Teclaff, 1973; Pearce,1992). The first irrigation canals to transport water from the Tigris and Euphrates were constructed more than 6000 years ago (Pearce,1992). The Nahrwan Canal, which ran alongside the Tigris for 400 km, the 600 km-long Pallacopas Canal that diverted the floodwaters of the Euphrates into the nearby Chaldean Marshes and the Shatt-el-Hai Canal joining the Tigris and Euphrates rivers approximately 4500 years ago (Warnick, 1969), are examples of early diversion schemes that illustrate the level of engineering skills possessed by this early civilisation. A time of plenty followed the development of irrigation and water transfer canals in Mesopotamia, but this period was not to last forever. By 3800 years BP, a progressive deterioration of crops was recorded. The wheat crops failed first, followed by barley, due to the salinisation of soils as a result of excessive irrigation practices. The Persians later employed improved irrigation practices: they watered less, and grew weeds to lower the water table and to keep the salty water from the roots of the crops. The Persian engineers, however, were themselves foiled by siltation in their extensive canal systems and ultimately, the desert returned.

Almost 5400 years ago, in Egypt, the left bank of the Nile was reclaimed for the cultivation of crops, while the right bank remained uncultivated for the dissipation of floodwaters (Samaha, 1979). A few hundred years later, the Pharaohs reclaimed the right bank of the Nile and the river was confined to its main channel. The first evidence of irrigation canals in the Nile Basin dates back to 5100 years ago. By this time, trenches had been dug to take water and fertile silt from the river to the irrigated fields. These trenches were much shorter than their equivalents in Mesopotamia, due to the narrower Nile valley. The flood irrigation system (i.e. flooding, siltation, and, subsequently, ploughing, sowing and harvesting before the next flood), which worked with the orderly progression of seasons and flood events, and which relied on natural drainage patterns with few canals, proved to be a sustainable system. The construction of a canal from the Nile River in Egypt to the Faiyum Depression dates back approximately 4000 years. The filling of the depression with silt-rich water constantly replenished the fertility of the land, and during times of low flow, the depression acted as an off-channel reservoir for Nile floodwaters. With the subsequent advent of perennial irrigation, however, a system that defies the natural sequence of seasons, came environmental degradation, and the need arose to build dams and waterworks in the Nile River basin to overcome the resultant water shortages.

The Egyptians, followed by the Romans, were the first civilisations to investigate new and more complex techniques to transfer water to its place of use. In the case of Egyptian culture, labour-saving techniques such as the pivoted *shaduf* and the animal-driven Archimedes screw, were used to lift water from the river (or wells) to irrigation canals and, hence, onto the fields. The Romans, with their knowledge of the equilibrium and pressure of water, built aqueducts that revolutionised municipal water supply, and transported water over large distances.

The Yellow River in China was already surrounded by dikes and irrigation canals 4000 years BP, in an attempt to harness the floodwaters of the river and to transport the water to the agricultural areas. The Beijing-Hangzhou Grand Canal, covering a distance of 1780 km, was built at the end of the 13th century, linking five river basins, including the Hai He, Yellow (Huang He), Huai He, Yangtze (Chang Jiang) and Qianting Jiang rivers, and transferring water from the Yangtze at Jiangdu to the dry North China Plain (Changming *et al*., 1985; Changming and Dakang, 1987). The Grand Canal was designed as a shipping channel that flowed from the Yangtze in the south to the Yellow River in the north (Hangzhou to Beijing). Reservoirs were built along its length in order to feed the upper sections. The first lock-gates were built on the Grand Canal, to allow boats to enter it from the Huai River. The purpose of this ambitious water project was to allow the transport of grain from the warm south to the cooler and drier regions in the north. Its annual transport capacity, by the end of the 13th century, was 400 000 tonnes of grain, and the canal reached Beijing.

In the 9th and 10th centuries, canals and reservoirs were being constructed to control the rivers within the flooded jungles of Cambodia. The schemes encouraged trade, controlled monsoon floods, and allowed the productivity of the rice paddies to rise to three or four crops a year (Teclaff and Teclaff, 1973). At the same time in Sri Lanka, King Parakramabahu was responsible for the construction of 1400 reservoirs and 500 canals, and a waterway known as the Ellahara, which links many of the country's large reservoirs (Pearce,1992). Also, in Anuradhapura, there are three reservoirs which date back 2000 years, and which receive their water from canals that extend more than 80 kilometres into the nearby hills to capture runoff.

In India, the mass transfer of water over long distances has been taking place for the last five centuries (Gole and Murphy, 1978). Examples of this are the Western Yamuna Canal and the Agra Canal, both built in Mughal times to transport water from the Himalayas to drier regions such as Punjab, Uttar Pradesh and Rajasthan. More recently, in the last century, the west-flowing rivers in the south-western region of India, Kerala, were diverted to the dry plateau in the east of the country. In the same period, other rivers such as the Ganga, Godavari and Krishna, were diverted through extensive canal systems, in order to irrigate distant and drier lands.

In countries well-endowed with water, the development of water-supply technology has lagged behind drier regions, because of the adequacy of water resources and their proximity to points of use. With the Industrial Revolution and the dramatic increase in demand for industrial, municipal and rural water supplies, and for irrigated agriculture, however, the next stage in the development of water resources commenced. With the marked increase in water consumption, even those regions which had been perceived as being water-rich began to encounter problems of water supply: parts of Europe, the eastern United States and South Africa, for instance. Currently, the rate and scale of development of water resources and associated environmental degradation, is far greater than has ever been the case in the past. It is only in the recent technological age that the manipulation and use of the earth's natural resources has expanded at a rate that is unsustainable. This is hardly surprising given the extraordinary advances in resource-exploitation techniques and transport systems and the growth of human populations.

1.3 Definitions

1.3.1 Types of IBT

For the purposes of this review we have chosen to adopt the definitions and approaches to IBTs of Davies *et al*. (1992). This paper tackled IBTs from a broad perspective. We have paraphrased some of the introduction to it in the following paragraphs.

Long-distance water transfer, inter-regional water transfer, large-scale water transfer, inter-catchment water transfer, inter-basin water transfer, and intra-basin water transfer, are all terms used to describe the transfer of water from an area of surplus to one where water demands have exceeded, or soon will exceed, supply (e.g. Cummings, 1974; Golubev and Biswas, 1978, 1985; Biswas *et al*., 1983; El-Ashry and Gibbons, 1988). In attempting to establish guide-lines for identifying water transfers in Canada, Quinn (1981) used two major criteria to define an IBT:

1. “The diverted flow does not return to the stream of origin, or to the parent stream within 20 km of the point of withdrawal; and

2. The mean annual flow transferred is not less than 0.5 $m^3 s^{-1}$.”

In their development of a definition of inter-basin water transfers, Davies *et al*. (1992) took a view contrary to Quinn (1981), arguing against any distance and volume component for any definition, because even apparently small instantaneous volumes could amount to considerable volumes, annually. Furthermore, Quinn’s definition makes no allowance for the effects of apparently low discharges from small IBTs on very small recipient systems. In addition, the flow volumes of many transfers vary enormously both temporally and spatially, dictating a broadening of the definition. Davies *et al*. (1992) further argue that IBTs may also be *intermittent* or *pulsed* in terms of their delivery, and that they may also vary widely on a seasonal basis. Also of concern to Davies *et al*. (1992) was the fact that *intra*-basin transfers, though common, are omitted from Quinn’s definition: the very frequency of occurrence of intra-basin transfers on a global basis dictates that they should not fall outside any definition of IBTs.

Following Davies *et al*. (1992), and accepting their arguments, we have adopted a definition of an inter-basin transfer of water as:

“*...the transfer of water from one geographically distinct river catchment or basin to another, or from one river reach to another*.”

In this way water transfer schemes, such as the Jonglei Canal on the River Nile (Egypt), the Grootdraai Emergency Scheme on the Vaal River (South Africa), and the diversion of the River Danube

(Hungary/Slovakia), which constitute major human manipulations of water *within* distinct basins, also constitute manipulations that will have major ecological repercussions (see e.g. Critchfield, 1978; Charnock 1983; Bailey and Cobb, 1984; Pearce, 1994; Snaddon *et al*., 1998). Some of these are addressed in Chapter 3 of this report.

Using the underlying tenet of river ecosystem functioning, the River Continuum Concept (RCC) of Vannote *et al*. (1980) which states that all rivers exhibit a gradation of biotic responses to a continuum of physical and chemical gradients, such that stream communities are variously structured and controlled down the system by the events that take place in upstream reaches, Davies *et al*. (1992) developed a schematic approach to the many and varied types of IBT in existence. This schematic is shown in Figure 1.1 and illustrates the fact that there are 15 basic types of IBT based on the RCC model, assuming that the removal or addition of water at any point along a river is likely to perturb the river continuum. If the broad types of delivery are added to this picture, for instance, constant *versus* pulsed systems, and seasonal *versus* unseasonal deliveries, or abstractions, Davies *et al*. (1992) illustrated the fact that, overall, the ultimate variety of types of IBTs assumed enormous complexity, with well over 60 different permutations (Figure 1.1).

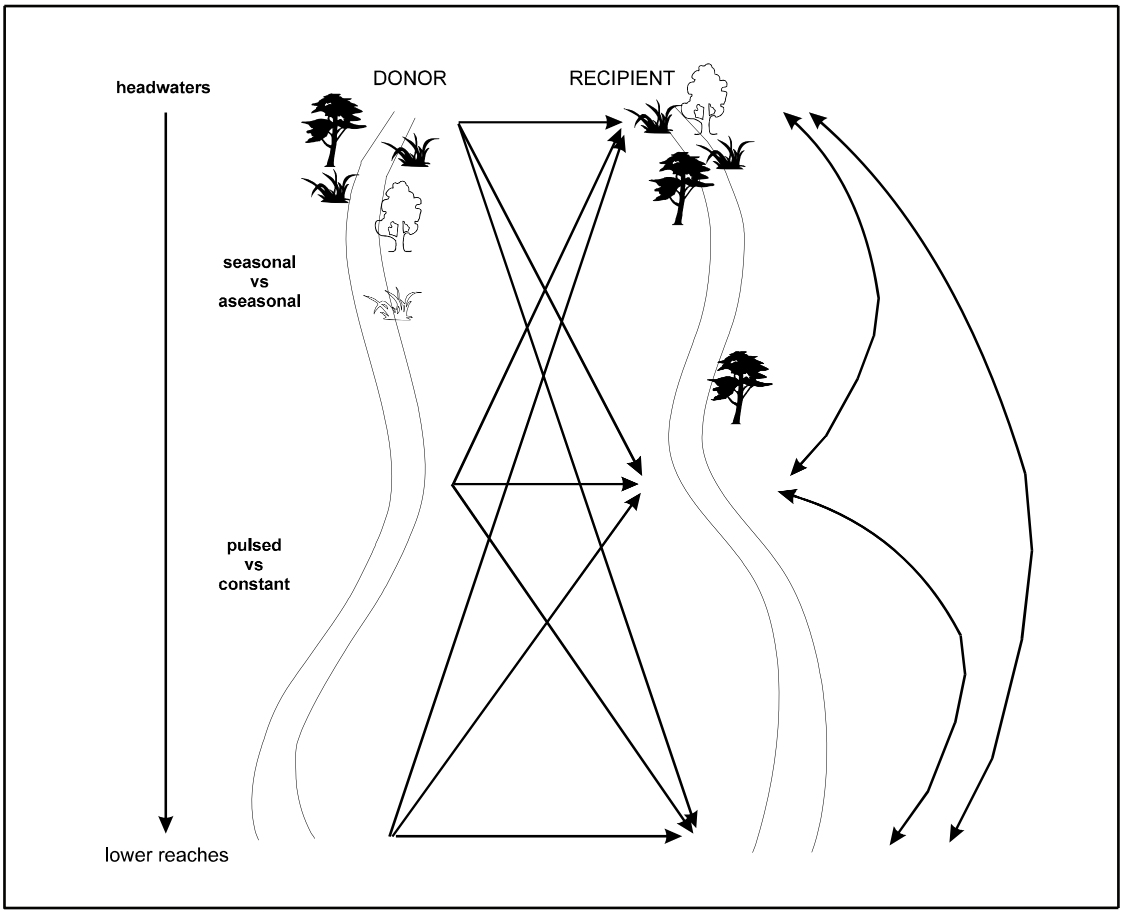

Figure 1.1 A schematic diagram showing the potential combinations of inter-basin water transfer, as defined by Davies *et al*. (1992). Transfers occur within or between rivers, and to and from different reaches; the duration of the transfer is either constant or pulsed, and occurs seasonally or aseasonally (irregularly throughout the year) (modified from Davies *et al*., 1992).

Although IBT types are adequately covered in their paper, particularly with regard to both donor and recipient rivers, Davies *et al*. (1992) and, indeed other authors, have failed adequately to address a third major component of any IBT: the transfer route. As a first attempt to redress this imbalance, Figure 1.2 has been developed for this review. It shows some of the concerns that we have uncovered for this component of our consideration of IBTs. Within the framework of the 60 or so different types of IBT, when the type of transfer route, or method of transfer, is added to the diversity of transfer schemes, the very large number of permutations developed by Davies *et al*. (1992) rapidly approaches overwhelming proportions. An IBT-transfer route may take any one, or even a combination, of three forms: canal, pipeline, or an existing river channel (Figure 1.2). Each of these routes of transfer may also, in turn, vary enormously.

For instance, a canal may be raised or sunk, open or covered, fenced or unfenced, possess ramps or have no ramps, and may be lined (with a wide variety of materials) or unlined, and so on. All of these variations can (and must) have different effects. Canals may also be reversible in terms of flow direction, through pumps, lifts and other devices. A pipeline, too, may allow flow reversal, and it can be buried as well as raised, or even be laid on the surface, and it may be constructed of a variety of materials each of which may have its own effects on flow, water quality, and so on (Figure 1.2). For example, Russian scientists have addressed the problems associated with water quality in lined transfer canals, and specifically the growth of filamentous algae in these canals and the associated deterioration in water quality (Oksiyuk *et al.*, 1979, 1981). Existing river channels will rarely have the capacity for flow reversal, but they vary considerably in terms of size, water quality and many other variables, all of which would have effects on the nature of the water ultimately delivered to the recipient river system.

Over and above these considerations, the length of the transfer route may greatly influence the effects of IBTs on recipient systems and the routes of transfer themselves. For example, in the case of very large IBTs where transfer routes may span thousands, rather than tens or hundreds of kilometres, a variety of other factors may confound the already complex and difficult task of assessing the ecological impacts of IBTs. Amongst these considerations is the possibility that water will be transferred across:

- Altitudinal gradients;
- Geological zones;
- Ecotones;
- Biogeographic regions, or bioregions (see Brown *et al*., 1996);
- Biotic sub-regions (Brown *et al*., 1996); and
- Water chemistry management regions (see Day and Dallas, 1996).

Finally, not all transfers solely involve rivers: in some instances they may involve the transfer of groundwater, or the movement of lake/wetland waters across catchment divides, to recipient rivers. These in turn will have very different implications for the impacts and future management of IBTs in terms both of the impacts on donor and recipient systems.

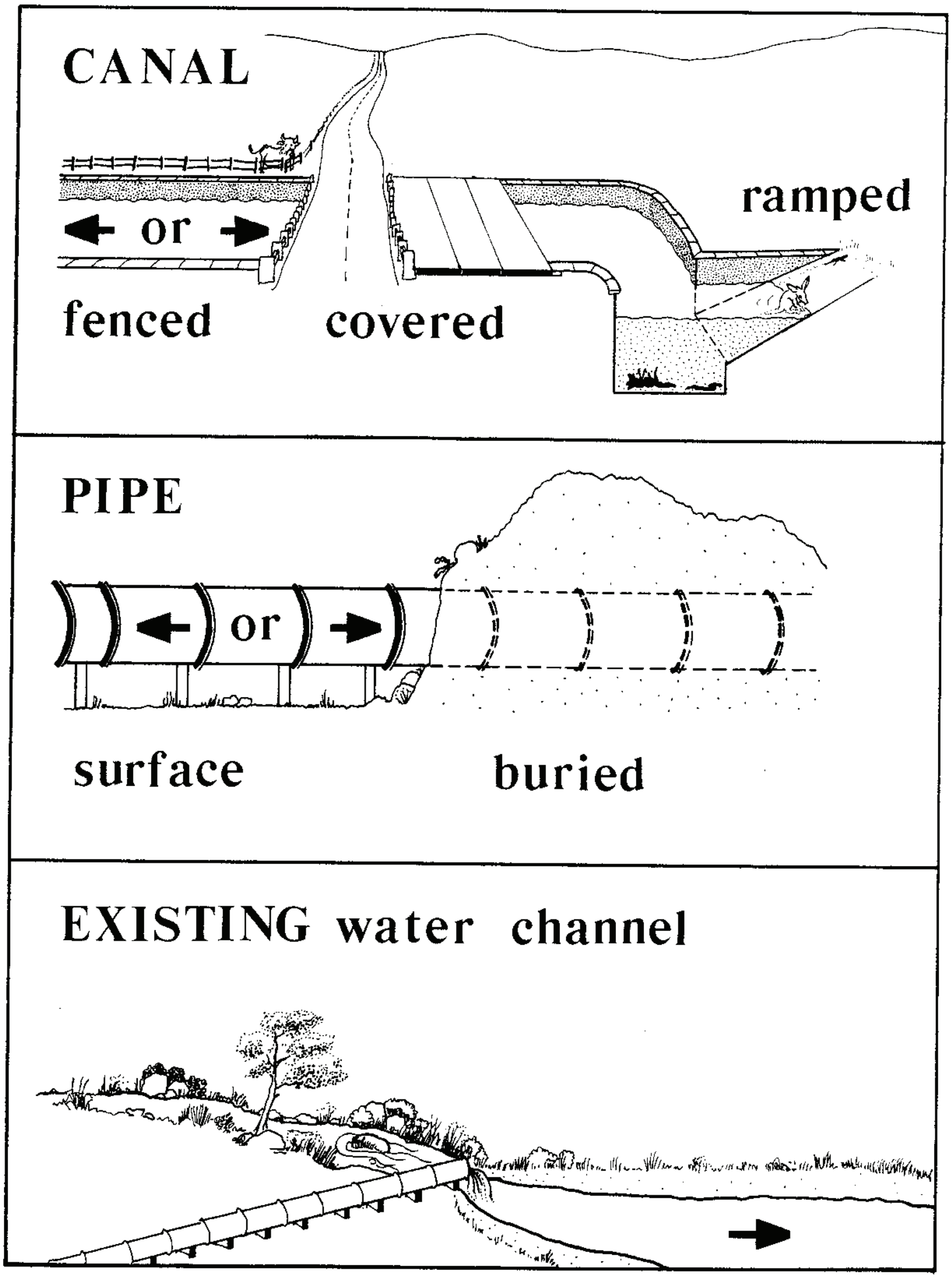

Figure 1.2 There is a variety of water transfer routes utilised in IBTs. These include canals, which can be open or covered, with fences and ramps, to provide an exit for trapped animals; pipes which are buried or laid on the surface, and existing water channels which are often used to transport the diverted water to and from storage reservoirs. The direction of the water through canals and pipes can, in some cases, be reversed.

1.3.2 Concepts of Recovery and Reset

Having broadened and clarified the definition of what constitutes an inter-basin transfer of water, Davies *et al.* (1992) widened the approach still further by pointing out that IBTs constituted facets of river regulation for which there already existed a theoretical base. This base is embodied in the Serial Discontinuity Concept (SDC: Ward and Stanford, 1983 - Figure 1.3) and builds upon the RCC by assuming that the latter has some foundation. The SDC states that impoundments act as *discontinuities* of the river continuum, and that all measurable characteristics of streams will have a "reset" or "recovery distance" (*sensu* O'Keeffe *et al.*, 1990) associated with it. For example, temperature, will be profoundly influenced by the level from which reservoir water is released into a receiving reach (elevated by surface-releases; depressed by deep-releases). However, such temperature changes should eventually equilibrate to pre-impoundment values after a given distance downstream. Similar types of disruption of the River Continuum must also occur in the case of IBTs. For example, Davies *et al.* (1992) have argued that a cold headwater transfer to a warmer mid-reach (Figure 1.1) would also disrupt the continuum, but in applying river regulation theory, must also have a recovery distance, or, in the case of some variables, even a multiplying effect (Figure 1.4). The same may be true for many other stream characteristics, such as water quality, nutrients and so on (Figure 1.4). The impacts of intra-basin water transfers, where water has not been moved from the basin but is simply relocated within it, can be just as ecologically deleterious as any major transfer (see for example, Ward and Stanford, 1979; Lillehammer and Saltviet, 1984; Petts, 1984; Davies and Walker, 1986; Craig and Kemper, 1987).

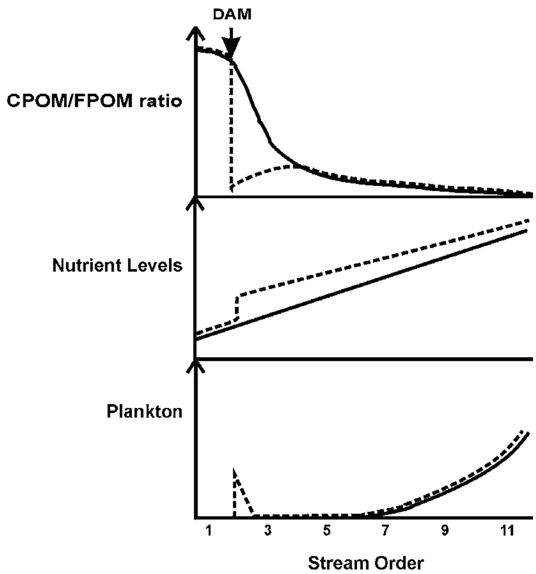

Figure 1.3 An illustration of three of the predictions of the Serial Discontinuity Concept (SDC: Ward and Stanford, 1983), which suggest that the release of water from a dam on the upper reaches of a river will lead to (a) a substantial drop in the ratio of coarse to fine particulate organic matter (CPOM:FPOM), (b), an increase in nutrient levels and (c) an introduction of zooplanktonic groups below the dam (adapted from Ward and Stanford, 1983).

In the temporal context, many IBTs cease for some part of the year, especially where the reason for transfer is irrigation. Thus, the rivers involved, if not impounded, will have the opportunity to recover to a certain extent, before transfer recommences (Snaddon, 1998; Snaddon and Davies, 1998). This recovery will depend on several factors such as the robustness of the systems (Hildrew and Giller, 1994), the period during which the transfer ceases and the timing of releases (Snaddon, 1998).

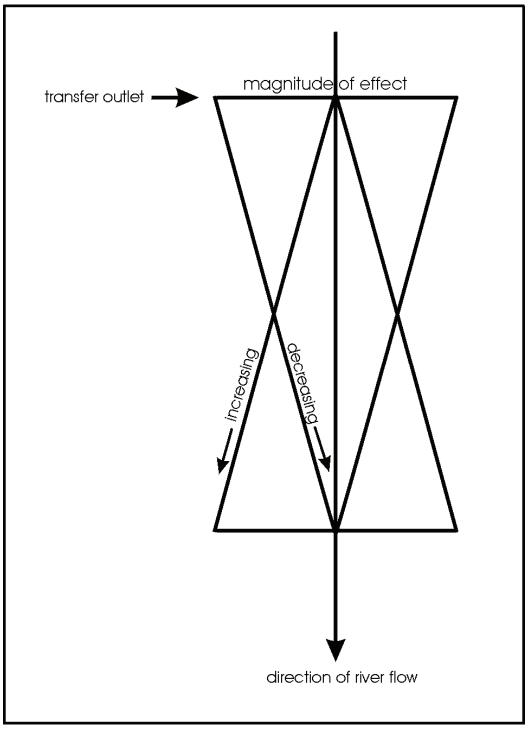

Figure 1.4 A graphic representation of two scenarios, where the magnitude of an effect of an IBT either increases or decreases down the length of a recipient river, leading to a multiplying effect or recovery with distance from the transfer outlet.

Given that these arguments are well-founded, the application of river ecosystem theory, including the RCC and SDC is not only possible, but, coupled with the recovery aspects of the SDC, should have important implications for the design of future IBTs and for the design, operation and management of extant schemes.

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2. GLOBAL OVERVIEW OF IBTS

2.1 Continental Africa

2.1.1 North Africa and the Middle East

Africa is a continent of many and varied climatic zones, ranging from equatorial tropical rainforests, humid Mediterranean-type climatic zones to hyper-arid areas (e.g. Beadle, 1981). Most of the countries of North Africa, and also the Middle East, are arid to semi-arid, with few perennial rivers and groundwater sources. Historically, this has been the location of some of the more advanced early civilisations and fairly intense agricultural activities, thus, many of the earliest water diversion schemes were constructed here (see Section 1.2). Currently, water supplies no longer meet growing needs, and water engineers have proposed several IBTs in the region.

Egypt has a very low rainfall, and extensive agricultural lands, which are reliant on irrigation water from the Nile River (Samaha, 1979). Agriculture accounts for just under 50% of employment and 80% of export earnings. The population is growing at a rate of 2.5%, and is expected to reach 70 million by the end of the century. Irrigation needs in the past have always been met through the construction of canals extending from the Nile. Since the turn of the century, however, water has been stored in at least three major impoundments (Samaha, 1979). The first of these, the Aswan Dam, was built on the Nile in Egypt, in 1902, with a storage capacity of 1×10^9 m^3, which increased to 2.5×10^9 m^3 by 1913. The Gabal El Awlia reservoir, which is situated in Sudan on the White Nile but provides water to Egypt, was built in the 1930s. More recently, the Aswan High Dam has been constructed south of the old Aswan Dam site, with a storage capacity of 162×10^9 m^3 (Figure 2.1) . Although none of these reservoirs contributes directly to IBTs, they store water which is transferred by canal to irrigated areas in other basins.

Two major canals have been constructed in Egypt to convey water between basins. In 1862, the Ismailia Canal was built connecting the Nile and the Suez Canal (Samaha, 1979) (Figure 2.1). This 128 km-long canal created a navigable route between the Nile and the Suez, while providing irrigation and potable water along its route. A few years later, in 1873, the Ibrahimia Canal was built along the left bank of the Nile, and runs for 61 km before splitting into four branches, one of which enters the Fayoum Depression, a shallow basin where water can be stored (Figure 2.1).

In southern Sudan, the Jonglei Canal was constructed in the early 1980s, although the scheme has never reached completion due to continued conflict in the area. This canal currently diverts 20% of the flow in the White Nile around the Sudd swamps, to irrigate cultivated areas in Egypt and Sudan (Critchfield, 1978; Charnock, 1983). The canal covers a distance of 360 km, and can deliver 4×10^9 m^3 yr^{-1}, some of which is returned to the White Nile further downstream (Bailey and Cobb, 1984) (Figure 2.1; Table 2.1). Sudan and Egypt were concerned that much of the water in the White Nile was being lost through evaporation from the Sudd swamps, and hence, by bypassing these swamps, this water could be put to greater use elsewhere. (Bailey and Cobb, 1984). Interestingly, the name “Sudd” is Arabic for blockage or barrier (Brown *et al*., 1984).

As with all arid and semi-arid countries, Libya has low and very variable rainfall (El Asswad, 1995). The rainfall ranges from 150 to 400 mm yr^{-1}, with most of it falling in the coastal region from September through to April. Due to strong winds and high temperatures, most of the available water is lost through evaporation, while only 5-10% recharges the groundwater resources, and 30-40% reaches the sea as surface runoff. Groundwater constitutes the major water resource in Libya, with 95% of the total amount of available water being derived from this source. Agriculture consumes nearly 99% of this available water, and the demand for water has doubled over the last 17 years, thereby placing great pressure on this very limited resource.

An ambitious water diversion project has been planned in order to alleviate the water deficits in the northern, coastal regions of Libya, where most of the irrigated agriculture in the country occurs (El Asswad, 1995). The scheme comprises three stages which will eventually transfer a combined total of 820×10^9 m^3 yr^{-1} from the regions of Alkufrah, Assarir and Fezzan, in the southern parts of Libya, northwards to the coast (Figure 2.1; Table 2.1). The concrete pipes will extend for 4500 km, costing a total of US $900 000. The first stage is complete, transferring 730×10^6 m^3 yr^{-1} for irrigation of a region along the north-eastern coast of Libya. This transfer scheme is expected to meet demands for the next 50 years (El Asswad, 1995).

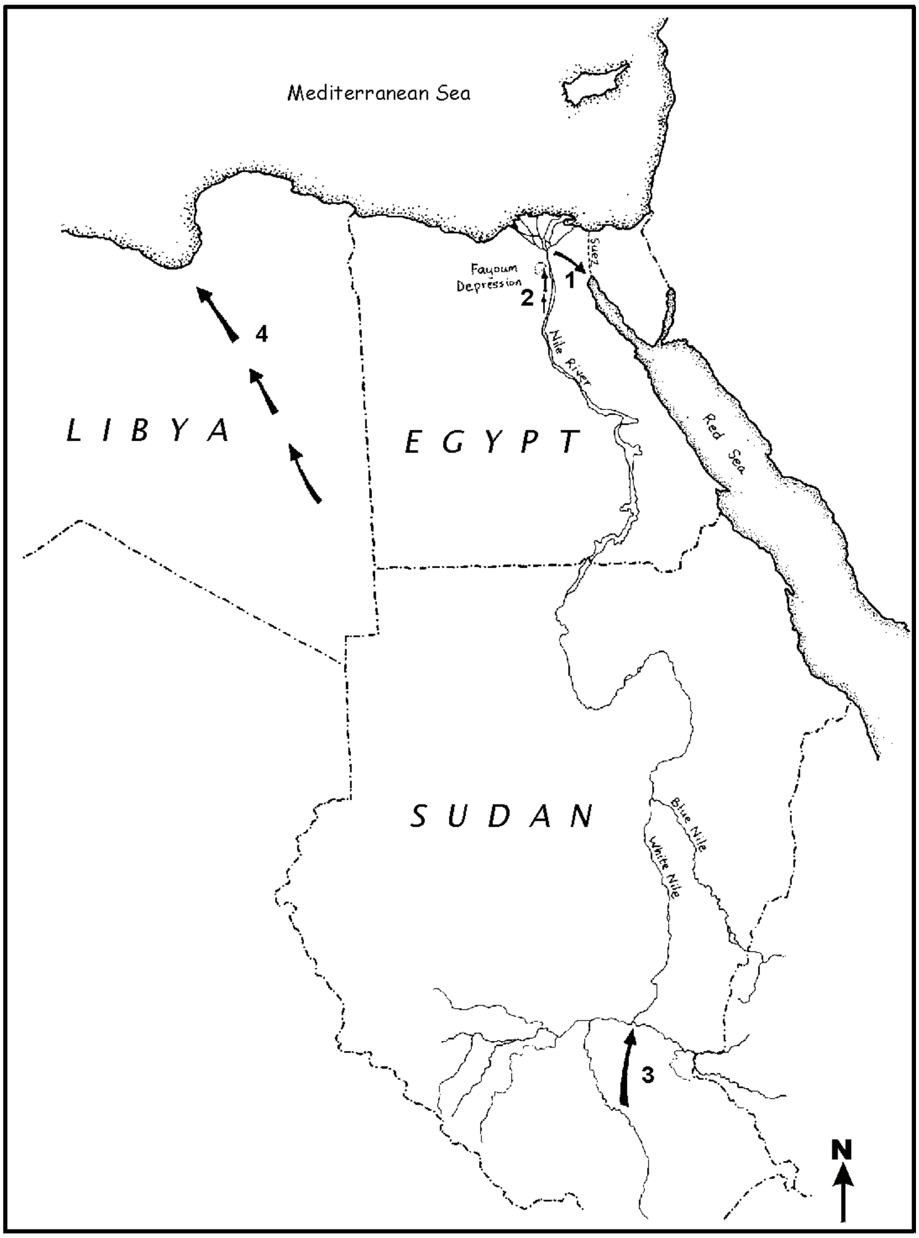


Figure 2.1 A map of eastern North Africa, showing the location of the IBT schemes in Libya, Egypt and Sudan, described in the text. 1, Ismailia Canal (Egypt); 2, Ibrahimia Canal (Egypt); 3, Jonglei Project (Sudan); 4, Great Man-made River Project (Libya).

Jordan is the driest country in the Middle East, with few rivers and a desert climate. While most of the Middle East countries harvest two or three crops a year, Jordan manages only one. Historically, the Jordan River was the only perennial source of water in the country. In the mid-1960s, however, Israel constructed its National Water Carrier, and diverted most of the river's 1200×10^6 m^3 annual flow for irrigation in that country (Pearce, 1995b) (Figure 2.2; Table 2.1). The National Water Carrier is the transfer route of the Jordan River Project in Israel, which transfers water from the Sea of Galilee (Lake Kinneret) to the central and southern coastal plain (Overman, 1976; Ambroggi, 1977; Gavaghan, 1986). This IBT supplies water to the city of Tel Aviv, and the Negev region, where it is needed for agricultural purposes.

The country of Jordan has had to turn to groundwater supplies for its own water needs. Furthermore, the level of the Dead Sea, supplied by the Jordan River, has been dropping by half a metre every year since the 1960s. Before his death, King Hussein of Jordan proposed the construction of a "Red-Dead" canal, which would link the Dead Sea with the Red Sea, further south (Figure 2.2). A 240 km canal would link the two systems, and bring water inland to fill the Dead Sea (Pearce, 1995b).

A further IBT proposal involves the diversion of water from the Litani River in southern Lebanon, to the headwaters of the Jordan River (Ambroggi, 1977; Pearce, 1995b) (Figure 2.2). The proposal suggests that the water should be kept in a "water bank", which would be jointly managed by the governments of the Middle East region. Water would be allocated from the "bank" to countries in need.

An IBT that was designed by British engineers in 1951 has resulted in the partial diversion of the waters of the Euphrates and Tigris rivers in Iraq (Pearce, 1993a). Before diversion, snowmelt from the Turkish headwaters of the Tigris and Euphrates annually flooded the low-lying marshes near the coast, bringing nutrient-laden silt to major wetlands, known as the Howeiza, Amara and Hammar marshes and the Shatt-al Arab, which is home to the Ma'dan or 'Marsh Arabs'. The scheme was originally designed to 'reclaim' land from these vast marshes that naturally link the two rivers. Construction of the scheme began in 1953, with a 20 km canal being built which drained the saline and water-logged farmlands in the marshes. In December 1992, the canal was extended to 560 km, with a width of up to 1.2 to 2 km in places. This canal, known as the "Third River", cuts off more than 40 tributaries from the marshes, and has allowed the reclamation of some 1.5 x 10^6 ha of land for farming. The canal now cuts to the west of the Hammar Marsh, crosses the Euphrates in three pipes and eventually drains through a 90 m-wide channel into the Persian Gulf along the western edge of the Shatt-al Arab. Furthermore, a series of lock gates on the easterly Tigris can halt or lower the flow of this river and, together with the construction of levees and an additional 90 km-long canal, the water can be diverted away from the eastern Howeiza Marsh (Pearce, 1993b).

The Tigris and Euphrates rivers are linked by the Tharthar Development Project, which comprises three phases of water transfer (Table 2.1). Water is transferred from the Tigris River to the Tharthar Depression, and from here it is diverted to the Euphrates. In a third phase, water can be transferred back to the Tigris, if required (Figure 2.2).

Table 2.1 IBT schemes in North Africa and the Middle East.

Country	Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred ($10^6 m^3 yr^{-1}$)	Average Transfer Rate ($10^6 m^3 day^{-1}$)
Egypt	Jonglei Project	irrigation	-	Atem (Bahr El Jebel)	White Nile	4000	20
Libya	Great Man-made River Project	irrigation	-	Alkufrah/Assarir/ Fezzan regions	Coastal region	820 000	2
Israel	Jordan River Project	irrigation and municipal	-	Jordan River (Sea of Galilee)	Central and southern coastal plain	1200	-
Iraq	Tharthar Development Project	irrigation	I	Tigris	Tharthar Depression	-	-
			II	Tigris	Euphrates	500	-
			III	Tharthar Depression	Tigris	600	-
Proposed:							
Jordan	Red-Dead Canal	replenish Dead Sea	-	Red Sea	Dead Sea	-	-
Lebanon	-	general supply	-	Litani River	Jordan River	-	-

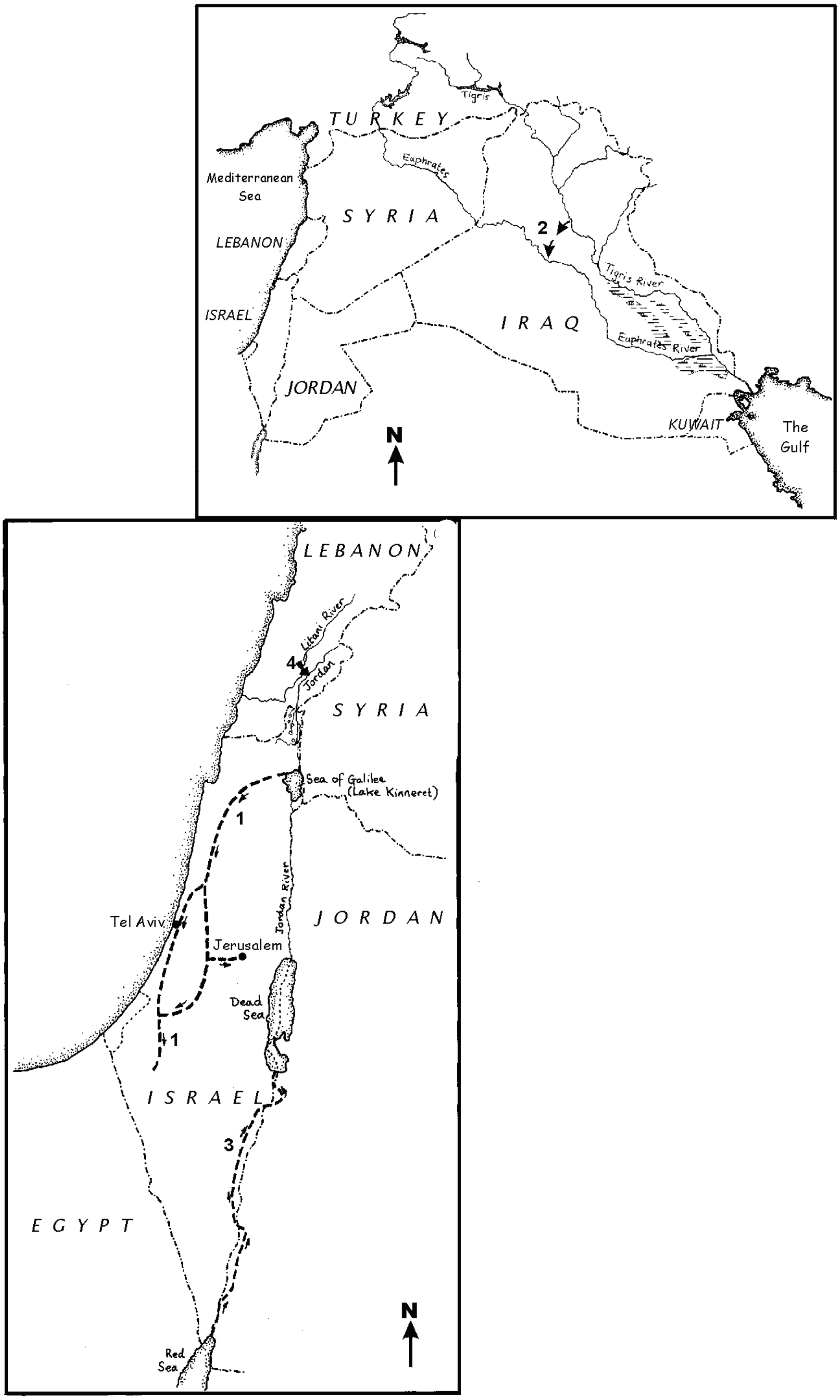


Figure 2.2 The location of the IBTs of the Middle East, mentioned in the text. 1, Jordan River Project; 2, Tharthar Development Project; 3, Red-Dead Canal; 4, Litani-Jordan Transfer.

2.1.2 Central and Tropical Africa

The authors have been unable to uncover any information on IBTs within this region of the African continent.

2.1.3 Southern Africa

The southern African region (comprising all countries south of 10°S; i.e. Angola, Botswana, the Democratic Republic of Congo, Lesotho, Malawi, Moçambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe) is considered a 'dryland' zone (*sensu* Davies *et al*., 1993b), with 37% of the planet's dryland zones occurring within the region (Thomas, 1989). Most of southern Africa can further be defined as water scarce (Basson, 1996; van Niekerk *et al*., 1996), where there are more than 600 people for every million cubic metres of available water per year (Falkenmark, 1993). The distribution of permanent surface-water resources, both lentic and lotic, varies substantially throughout southern Africa, such that vast areas are devoid of reliable water supplies (e.g. Gourou, 1970; Midgley, 1978; Figure 2.3).

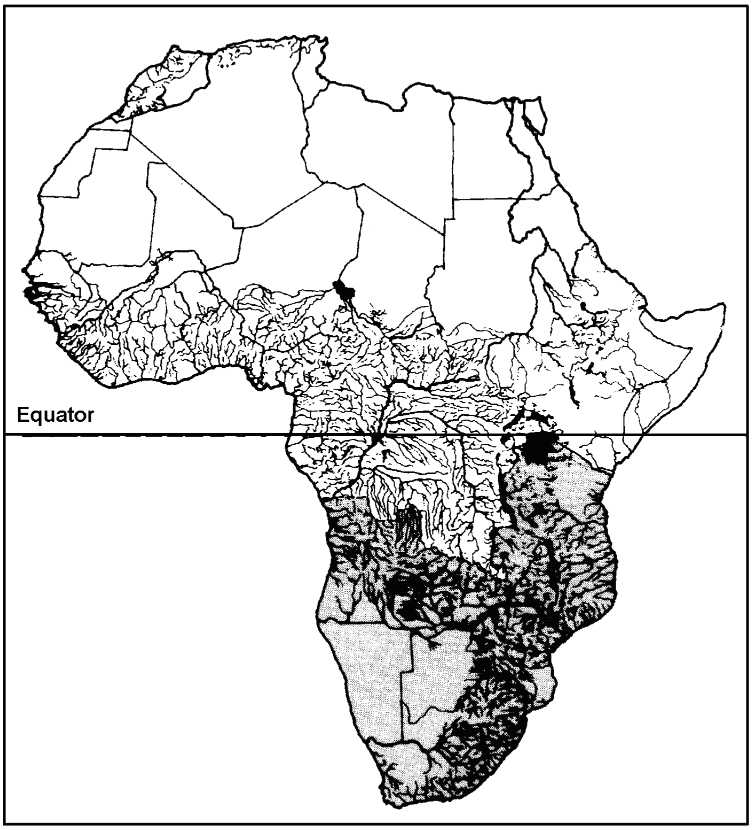


Figure 2.3 A map of the perennial river systems of Africa (from Gourou, 1970). SADC countries are shaded.

In addition, many of the rivers of southern Africa, and especially those in the south, are highly variable in terms of their hydrology (Alexander, 1985). Indeed, Davies *et al*. (1995) have described the rivers of southern Africa as 'predictably unpredictable'. This feature is largely a product of the extreme variability of rainfall and climatic patterns, and generally high to very high evaporation rates across the region (Table 2.2). The combination of hydrological variability and the peculiarities of population and urban distribution throughout the region, serve to make water-resources planning in southern Africa an extremely difficult task (Conley, 1995).

As a result of the continual human expansion throughout southern Africa, basic water demands have increased to the point where many river ecosystems have become greatly stressed. The demand for water throughout southern Africa is predicted to increase at a rate of 3% per annum up to the year 2020 (Heyns *et al*., 1994; Pitman and Hudson, 1994). Several countries in southern Africa, notably Botswana, Namibia, northern Moçambique, South Africa and Zimbabwe, already face water-supply shortages of considerable magnitude (Heyns *et al*., 1994). In the case of Namibia, a hyper-arid country, there are no assured permanent surface resources (e.g. Jacobson *et al.*, 1995; Figure 2.3) and major groundwater resources are over-exploited. In South Africa, problems related to water supply are exacerbated by the fact that many of the larger storages in the country, such as Gariep Dam on the Orange River, collect water reserves in areas where demand is low, and where there are both unpredictable runoff and very high evaporation rates (e.g. Alexander, 1985; Department of Water Affairs, 1986a; Davies and Day, 1986, 1998; Table 2.2). There is, therefore, growing pressure to look beyond catchment, provincial and national boundaries for more reliable supplies of water, and to create redistribution networks which transport water from areas of perceived surplus to those in deficit.

The transfer of water across catchments has been a component of river regulation in southern Africa for at least three decades, and almost all of the IBT schemes of the region fall within or across the borders of South Africa (Figure 2.4). South Africa accounts for the bulk of consumption on the subcontinent, while only 10% of the water is located here (Table 2.3).

Table 2.2 The average rainfall and ranges in rainfall and evaporation of most of the countries of southern Africa (after Heyns *et al*., 1994). The Deficit/Gain column is derived from the differences between the ranges of rainfall and evaporation.

Country	**Rainfall (mm yr^{-1})**		**Evaporation (mm yr^{-1})**	**Deficit/Gain**
	Average	**Range**	**Range**	**(mm yr^{-1})**
Angola	800	25 - 1600	1300 - 2600	-1275 - -1000
Botswana	400	250 - 650	2600 - 3700	-2350 - -3050
Lesotho	700	500 - 2000	1800 - 2100	-1300 - -100
Malawi	1000	700 - 2800	1800 - 2000	-1100 - 800
Moçambique	1100	350 - 2000	1100 - 2000	-750 - 0
Namibia	250	10 - 700	2600 - 3700	-3000 - -2590
South Africa	500	50 - 3000	1100 - 3000	-1050 - 0
Swaziland	800	500 - 1500	2000 - 2200	-1500 - -700
Tanzania	750	300 - 1600	1100 - 2000	-800 - -400
Zambia	800	700 - 1200	2000 - 2500	-1300
Zimbabwe	700	350 - 1000	2000 - 2600	-1650 - -1600

Table 2.3 Statistics on water availability and consumption in southern Africa (adapted from Conley, 1995). The proportion of water available and water used on the subcontinent by each country is provided as percentages.

Country	**Total Water Available (10^6 m^3)**	**% Total Water Available**	**Total Water Use (10^6 m^3 yr^{-1})**	**% Total Water Use**
Angola	158 000	32	480	2
Zambia	96 000	19	360	2
Tanzania	76 000	15	480	2
Moçambique	58 000	12	760	3
South Africa	50 000	10	19 040	84
Zimbabwe	23 000	5	1 220	5.5
Namibia	9 000	2	n/av*	n/av*
Botswana	9 000	2	90	0.4
Malawi	9 000	2	160	0.7
Swaziland	7 000	1.5	n/av*	n/av*
Lesotho	4 000	1	50	0.2
TOTAL	**499 000**	**100**	**22 640**	**100**

*n/av: not available

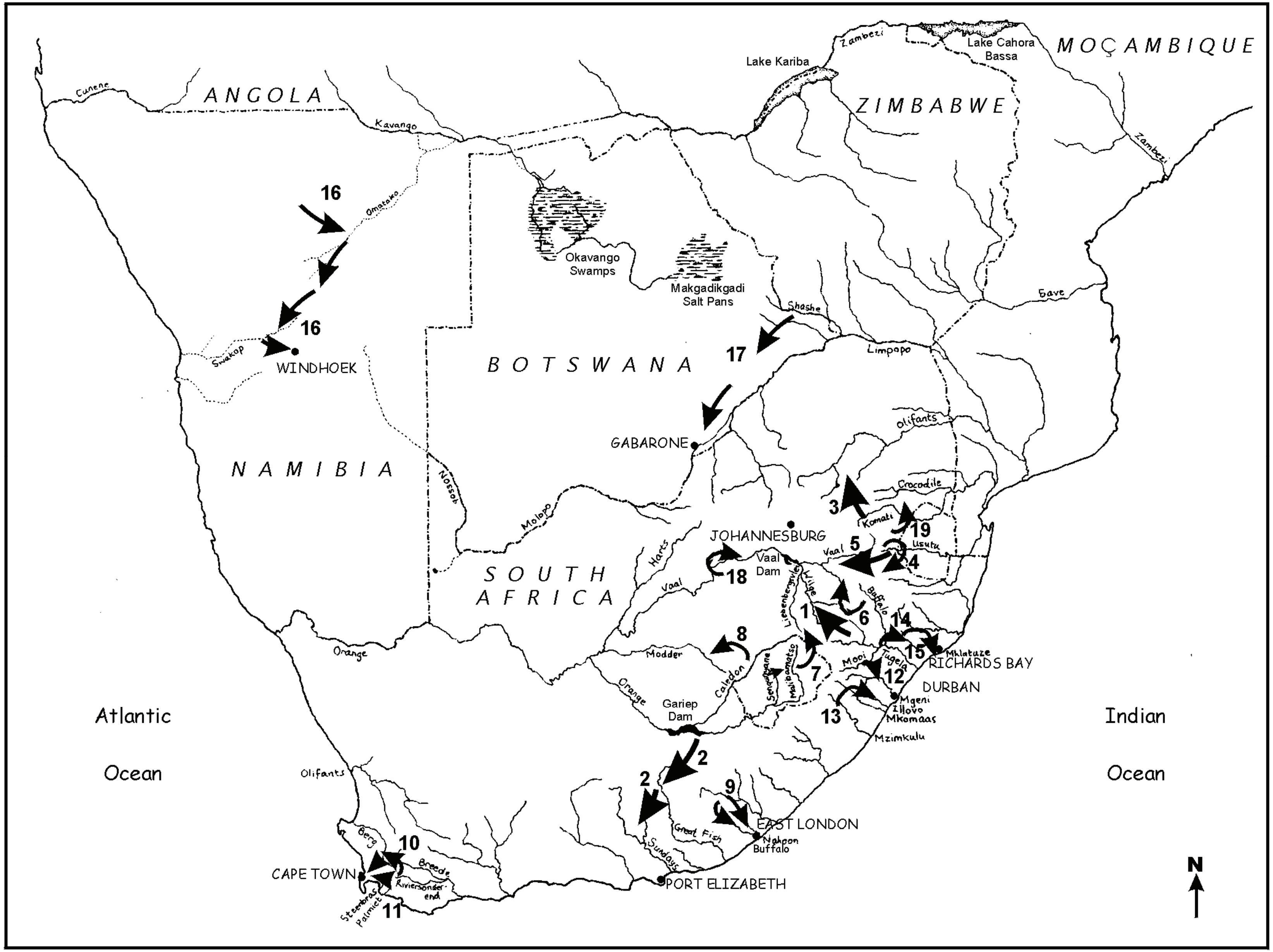


Figure 2.4 The IBTs of southern Africa. 1, Tugela-Vaal Scheme; 2, Orange River Project; 3, Komati Scheme; 4, Usutu Scheme; 5, Usutu-Vaal Scheme; 6, Slang River Scheme; 7, Lesotho Highlands Water Project; 8, Caledon-Modder Scheme; 9, Amatole Scheme; 10, Riviersonderend-Berg-Eerste River Government Water Scheme; 11, Palmiet River Scheme; 12, Mooi-Mgeni Scheme; 13, Mzimkulu-Mkomaas-Illovo Scheme; 14, Tugela-Mhlatuze Transfer Scheme; 15, Mhlatuze Scheme; 16, Eastern National Water Carrier; 17, North-South Water Carrier; 18, Grootdraai Emergency Scheme; 19, Sabie River Government Water Scheme.

Petitjean and Davies (1988a,b) reviewed the extant and planned IBTs for the subcontinent, and all the major transfers identified in their work, and in more recent work (e.g. Rowlston, 1991; Basson, 1997; Snaddon *et al.*, 1998), are illustrated in Figure 2.4, while Table 2.4 provides a list of both existing and potential IBTs in southern Africa. In 1988, the total volume involved in IBTs exceeded 1.63 x 10^9 m^3 yr^{-1}, and was predicted to rise to 4.82 x 10^9 m^3 yr^{-1}: this is almost equivalent to the total mean annual runoff (MAR) for the Western Cape Province of South Africa. As such, within South Africa, IBTs would harness 8.9% of the total MAR (Petitjean and Davies, 1988a,b; Davies *et al.*, 1992). The authors of this report have been reluctant to re-evaluate this total, as many of the transfer schemes are pulsed, and thus a total volume might be an overestimate.

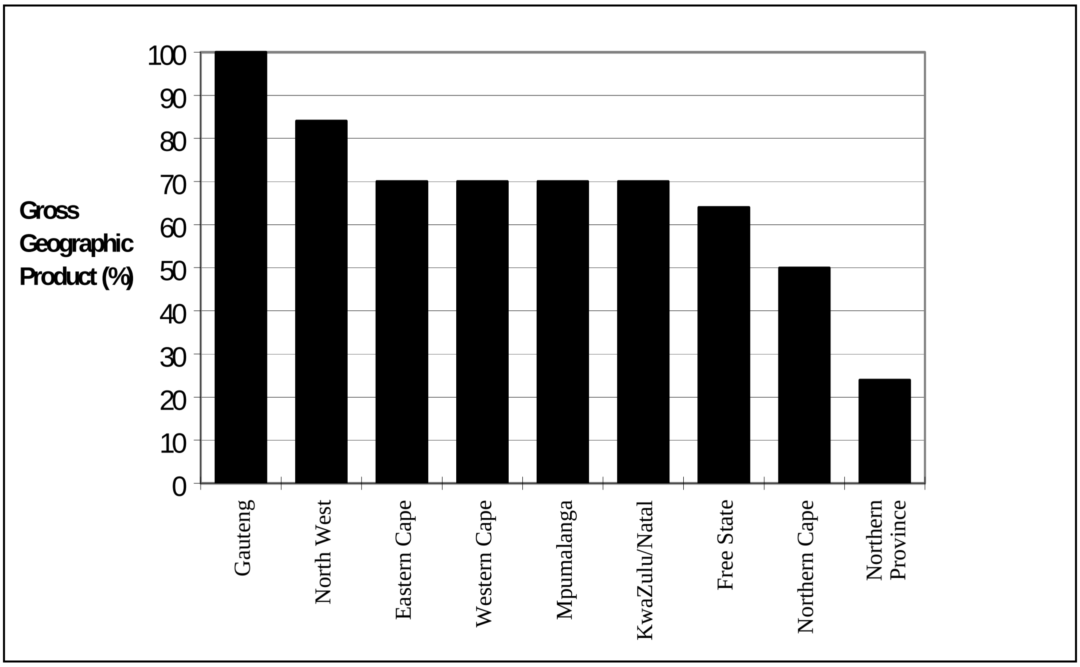


Figure 2.5 A graphic presentation of the percentage of South Africa's Gross Geographic Product (GGP), as an indicator of productivity per province, that is at least partly reliant on inter-basin water transfer schemes (from Van Niekerk *et al.* (1996)).

The significance of IBTs to water resources development in South Africa is clear from Figure 2.4, while Figure 2.5 illustrates the importance of these schemes to the economy of the country, in terms of the percentage of the 2.5 illustrates the importance of these schemes to the economy of the country, in terms of the percentage of the Gross Geographic Product (GGP) that is at least partially dependent on IBTs (Van Niekerk *et al.*, 1996; Basson, 1997). The major water demand in South Africa is located in Gauteng Province (Pretoria, Johannesburg, Vereeniging and satellite cities), in the catchments of the Vaal (south), the Crocodile (north), and the Olifants rivers (east). The city of Johannesburg itself is located quite a distance from any major rivers. Thus, it is not surprising that 100% of the GGP for Gauteng relies on water from other catchments. The Vaal River is presently augmented by several river basins, including the Tugela, Orange, Usutu, Komati, Olifants and Buffels rivers and, thus, almost 50% of water supply originates beyond the catchment boundaries (Pitman and Hudson, 1994; Van Niekerk *et al.*, 1996). As water demand increases in the catchment, further storages and diversions are being planned, not only from rivers within the country, but also from neighbouring Lesotho (Figure 2.4, Table 2.4).

The first major IBT to be built in South Africa was the Tugela-Vaal Scheme, which was completed in 1975 (Scheme 1 in Figure 2.4, Table 2.4). This scheme currently comprises Spioenkop Dam, which regulates the flow in the Tugela River for downstream users, while upstream, Woodstock Dam stores water to be pumped to the Vaal which can be delivered at a rate of 11 m^3 s^{-1} (Figure 2.6). On route to the Vaal, water from Woodstock Reservoir can temporarily be stored in the Sterkfontein Dam on the Nuwejaarsspruit, a small tributary of the Wilge River, which in turn flows into the Vaal. This additional storage, Sterkfontein, is considered to be particularly advantageous because of its situation high on the Drakensberg escarpment, which reduces evaporative losses. Thus water can be stored for long periods and released only when perceived necessary (Department of Water Affairs and Forestry, 1991b).

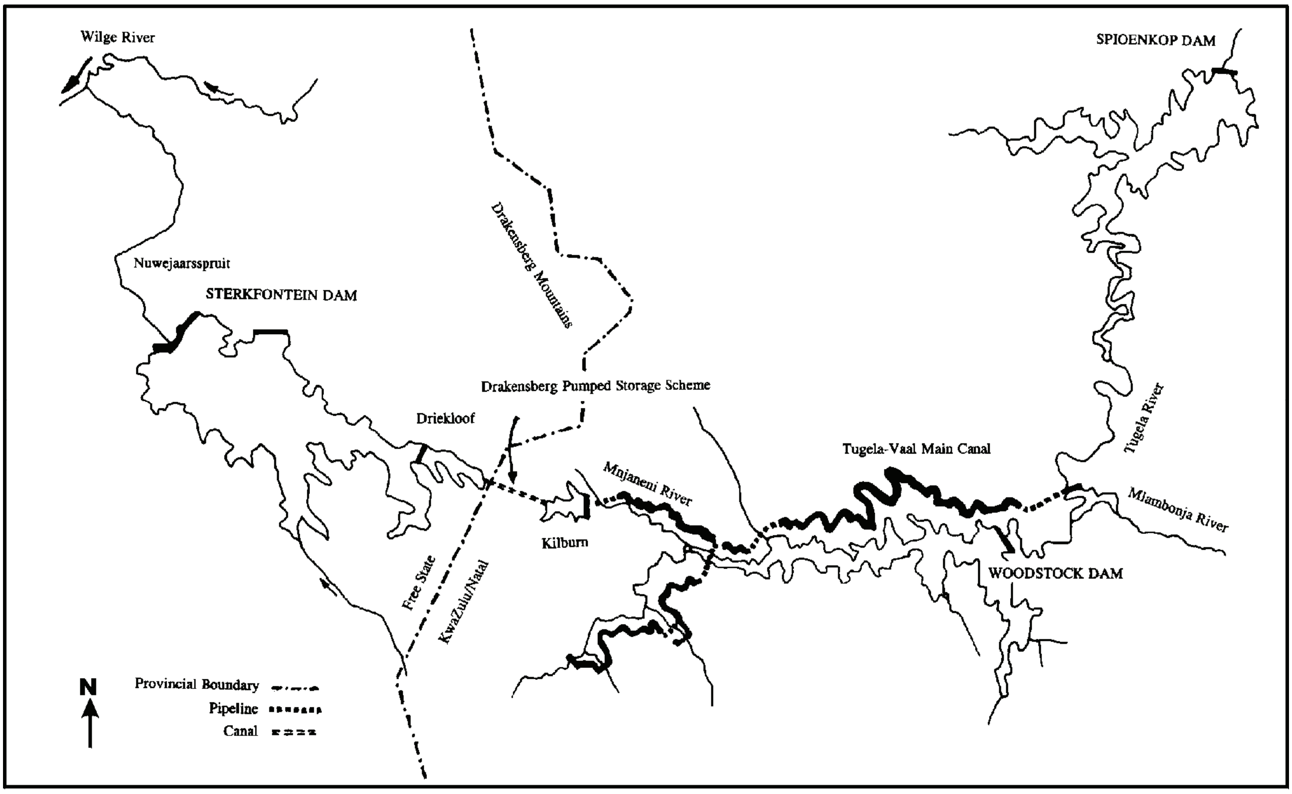


Figure 2.6 A map showing details of the Tugela-Vaal Transfer Scheme in South Africa (from Snaddon *et al.*, 1998).

An additional feature of this IBT comprises an underground hydro-electric power plant situated between Kilburn Reservoir, which lies on a tributary of the Tugela, and Driekloof Reservoir, which is situated above Sterkfontein Reservoir, at the top of the Drakensberg escarpment. During periods of peak energy demand, water can flow from Driekloof back into Kilburn Reservoir, thereby providing power, some of which drives the pumps for the IBT (Figure 2.6). In 1983, the Tugela-Vaal Scheme was expanded in order to provide a greater assurance of water supply to Gauteng, with an increase in the transfer rate to 20 $m^3 s^{-1}$ (Department of Water Affairs and Forestry, 1991b).

The Vaal River joins the westward-flowing Orange River, which similarly has been regulated by a major IBT. The Orange River Project (ORP) was the next scheme to be constructed in South Africa – this scheme currently transfers a maximum of 1.7×10^9 $m^3 yr^{-1}$ of water from the Orange River (which carries 13.5% of the MAR of the country) to the Great Fish and Sundays rivers in the Eastern Cape Province (Scheme 2 in Figure 2.4; Table 2.4). This scheme has been operational since 1977, and is primarily used for the provision of irrigation water in the recipient catchments, in addition to flood control and hydro-electric power generation. An 82 km-long tunnel extends from Gariep Reservoir to the Teebus River, a tributary of the upper Orange River. A further transfer, through a canal and tunnel system, occurs between Elandsdrift Dam, on the Great Fish, and the neighbouring Sundays River catchment (O'Keeffe and De Moor, 1988) (Figure 2.4).

Table 2.4 Some attributes of existing inter-basin transfer schemes in southern Africa, and those proposed or under construction. (Modified from Petitjean and Davies, 1988b). Note that the capital costs provided in this table are not comparable, as they have been distilled from a variety of sources, that provide estimates from a range of years.

Scheme	Purpose	Phase	Capital Cost (R million)	Donor river(s)	Recipient river(s)	Volume of transfer ($x10^6 m^3 yr^{-1}$)
Extant:						
Usutu Vaal River Government Water Scheme	electric power and general suppy	I II Emergency Scheme	- 84 -	Vaal Assegaai (Usutu) Assegaai (Usutu)	Steenkoolspruit (Olifants) Klein Vaal/Vaal Ngwempisi River (Usutu)	160 260 -
Grootdraai Dam Emergency Augmentation Scheme (1983)	emergency general supply	-	-	Vaal	Vaal	-
Usutu River Government Water Scheme	power station cooling	5 phases	-	Usutu Mpamaspruit (Usutu) Ngwempisi Spruit (Usutu) Bonnie Brook (Usutu)	Mpamaspruit (Usutu) Power station Mpamaspruit(Usutu) Usutu	103
Komati River Government Water Scheme	power station cooling	-	-	Komati	Olifants catchment power stations	131
Slang River Government Water Scheme	power station cooling	-	-	Slang (Buffalo)	Perdewaterspruit, Schulpspruit (Vaal)	-
Tugela-Vaal Scheme	general supply	I IIa IIb	- 566 -	Tugela Tugela Tugela	Nuwejaarsspruit (Vaal) Nuwejaarsspruit (Vaal Nuwejaarsspruit (Vaal)	160 347 631
Caledon-Modder Scheme	municipal and industrial supply	- -	- -	Caledon Caledon	Rietspruit (Caledon) Modder	 40
Lesotho Highlands Water Project	general supply	Ia	-	Malibamatso	Nqoe (Caledon)/Ash (Vaal)	533
Mhlatuze Government Water Scheme	municipal and industrial supply	-	-	Mhlatuze	Mhlatuze (Lake Nseze)	
Orange River Project	irrigation	- -	- -	Orange Great Fish to Little Fish	Teebus (Great Fish) Sundays	1 700 26
Riviersonderend-Berg-Eerste River Government Water Scheme	general supply	I & II III	- -	Riviersonderend (Breede) Riviersonderend (Breede)	Berg Eerste	0.5-5 $m^3 s^{-1}$ 130
Mooi-Mgeni Scheme	general supply	Mearns Emergency Pumping Scheme	-	Mooi (Tugela)	Mpofana (Mgeni)	3-30
Amatole Scheme	municipal supply	-	225	Toise & Kubusi	Yellowwoods & Nahoon	36
Palmiet River Scheme	general supply	I	676	Palmiet	Steenbras	22
Eastern National Water Carrier	municipal and general supply	I II III	- - -	Swakop Omatako Karstland boreholes	Windhoek area Swakop Omatako	 2 $m^3 s^{-1}$ 15-20

Table 2.4 continued…

Proposed:						
Scheme	**Purpose**	**Phase**	**Capital Cost (R million)**	**Donor river(s)**	**Recipient river(s)**	**Volume of transfer ($x10^6 m^3 yr^{-1}$)**
Lesotho Highlands Water Project	general supply	Ib Further Phases	- 25 000	Matsoku (Malibamatso)/Senqunyane Senqunyane (Orange)	Malibamatso/Ash (Vaal) Ash (Vaal)	851 2207
Palmiet River Scheme	general supply	II	-	Palmiet	Steenbras	127
Mooi-Mgeni Scheme	general supply	Ia Ib II	- - -	Mooi (Tugela) Mooi (Tugela) Mooi (Tugela)	Mpofana (Mgeni) Mpofana (Mgeni) Mpofana (Mgeni)	$3 m^3 s^{-1}$ $4\text{-}10 m^3 s^{-1}$ $6 m^3 s^{-1}$
Mzimkulu-Mkomaas-Illovo Scheme	municipal supply	I II	680 -	Mkomaas Mzimkulu	Mgeni & Illovo Mkomaas	375 -
Sabie River Government Water Scheme		I II	270 -	Marite Sand	Sand Sand/Klein Sand	25 -
The Zambezi Aqueduct	general supply	-	6000	Zambezi	Botswana & Vaal	2500 to 4000
Tugela-Mhlatuze Transfer	general supply	-	260	Tugela	Mhlatuze	-
Skuifraam Supplementary Scheme Misverstand Dam Raising Keerom Diversion	general supply	- - -	82 436 776	Berg Lower Berg Olifants	Upper Berg Voëlvlei Dam (Berg River catchment) Berg	19 70 90
Michell's Pass Diversion Molenaars River Diversion Brandvlei to Theewaterskloof Eastern National Water Carrier	general supply general supply	- - - IV	20 89 317 -	Breede Molenaars (Breede) Breede Kavango	Boontjies (Berg) Berg or Riviersonderend Riviersonderend Omatako	15 35 100 $2\text{-}3 m^3 s^{-1}$
North-South Water Carrier	general supply	-	-	Shashe	Eastern Botswana	-

The location of coal reserves in the interior of the country, and especially in the province of Mpumalanga, has led to the clustering of power stations in this area, and, therefore, the need for supplies of cooling water has resulted in a proliferation of smaller transfer schemes which supply these industrial catchments (Van Robbroeck, 1977; Department of Water Affairs and Forestry, 1991a). The Komati Scheme, for example, transfers $131 \times 10^6\ m^3\ yr^{-1}$ of water from a series of dams and weirs on the Komati River, to power stations in the Olifants River catchment (Scheme 4 in Figure 2.4; Table 2.4). The Komati River is an international river which flows from South Africa, through Swaziland and into Moçambique, where it is known as the Incomati (Van Robbroeck, 1977). The Usutu River was also regulated in a similar way, in the form of the Usutu Scheme, which transfers $103 \times 10^6\ m^3\ yr^{-1}$ to power stations within the Usutu River catchment (Scheme 3 in Figure 2.4; Table 2.4). The Usutu also flows through Swaziland and Moçambique, where it becomes the Maputo River. Neither of these schemes releases water into natural river channels, but both transport water along pipelines by pump and gravity (Rowlston, 1991).

The Usutu-Vaal Scheme comprises a series of links between these two river catchments, in order primarily to provide power station cooling water (Scheme 5 in Figure 2.4; Table 2.4). Water is transferred from Grootdraai Dam on the Vaal River, and across the divide between the Vaal and Olifants rivers, *via* a power plant, to the Steenkoolspruit (Department of Water Affairs and Forestry, 1991a) (Figure 2.3). A further component of the scheme transports water through a canal from the Heyshope Dam on the Assegaai River, in the Usutu catchment to the Klein Vaal River which then joins the Vaal. There also exists a gravity link from this canal to the Ngwempisi River in the Usutu catchment. This is an emergency measure which has seldom been used (Rowlston, 1991). A total of $420 \times 10^6\ m^3\ yr^{-1}$ can be transferred by the Usutu-Vaal Scheme. An additional transfer, the Slang River Scheme, provides water to a power station in the Vaal catchment. This scheme brings water from the Zaaihoek Dam on the Slang River, a tributary of the Buffalo River, to the Majuba Power Station in the Vaal catchment (Scheme 11 in Figure 2.4; Table 2.4). Surplus water can be released into two tributaries of the Vaal, the Perdewaterspruit or the Schulpspruit, or the Vaal River itself.

An international IBT in southern Africa has recently commenced its first phase of water transfer, in order further to augment water supplies in the Vaal River catchment. The Lesotho Highlands Water Project (LHWP), currently the largest IBT in continental Africa, is under construction at an estimated cost of *ca* \$US 7 billion (Scheme 12 in Figure 2.4, 2.7; Table 2.4). The scheme is designed ultimately to divert $2.2 \times 10^9\ m^3\ yr^{-1}$ of water from the headwaters of the Orange River in Lesotho, into the Ash (or Axle)/Liebenbergsvlei tributary of the Vaal River in the Free State (Department of Water Affairs, 1985; Petitjean and Davies, 1988a,b; Davies *et al*., 1992) (Figure 2.7). When this scheme is in operation, more than 75% of the flow of the Vaal will be imported from other catchments. The treaty for the Lesotho Highlands Water Project was signed on October 24, 1987, and was the subject of many years of international negotiations and technical investigations. The water will be used primarily for industrial and domestic consumption in Gauteng (the perceived 'high price' of the water - *ca* R0.7 m^{-3}- will preclude agricultural use), and the scheme will also generate hydro-electric power for use in Lesotho.

Phase 1 of the LHWP has two components. Phase IA comprises the Katse Dam, with a wall height of 182 m and small hydro-electric power unit, on the Malibamatso River, and the Muela Tailpond, also with a hydro-electric power unit, on the Nqoe River (Figure 2.7). Both reservoirs impound tributaries of the Orange River in Lesotho. This Phase also comprises two transfer tunnels, one of which connects Katse and Muela (48 km), while the other runs beneath the Caledon and Little Caledon rivers, from the Muela Tailpond to the Ash/Liebenbergsvlei River in South Africa (34 km). Phase 1B comprises the Mohale Dam (wall height, 146 m) which is presently in the early phases of construction across the Senqunyane River. It will be connected by a 32 km-long tunnel to Katse (Figure 2.7). This Phase also includes the Matsoku Diversion Weir on the Matsoku River, with an additional tunnel connecting the weir to Katse Dam (Lesotho Highlands Development Authority Annual Report, 1993/4). Construction of Katse Dam commenced in 1992, and on completion in 1997, it is the tallest such structure on the African Continent, surpassing Cahora Bassa by a few metres (Lesotho Highlands Water Project, 1992; Lesotho Highlands Development Authority Annual Report, 1993/4). A small hydro-electric power plant will be built into the base of Katse Dam, and will be driven by the compensation flow of a minimum of $0.5\ m^3\ s^{-1}$ released from the dam (Chutter, 1993). Further phases of the project may include the Mashai Dam on the Lower Malibamatso River and a tunnel connecting this impoundment to Katse *via* a pump station (Figure 2.7). Other dams and transfer options within the scheme are also possible, some of which are shown in Figure 2.7, although present indications point to the cessation of the project after Phase IB.

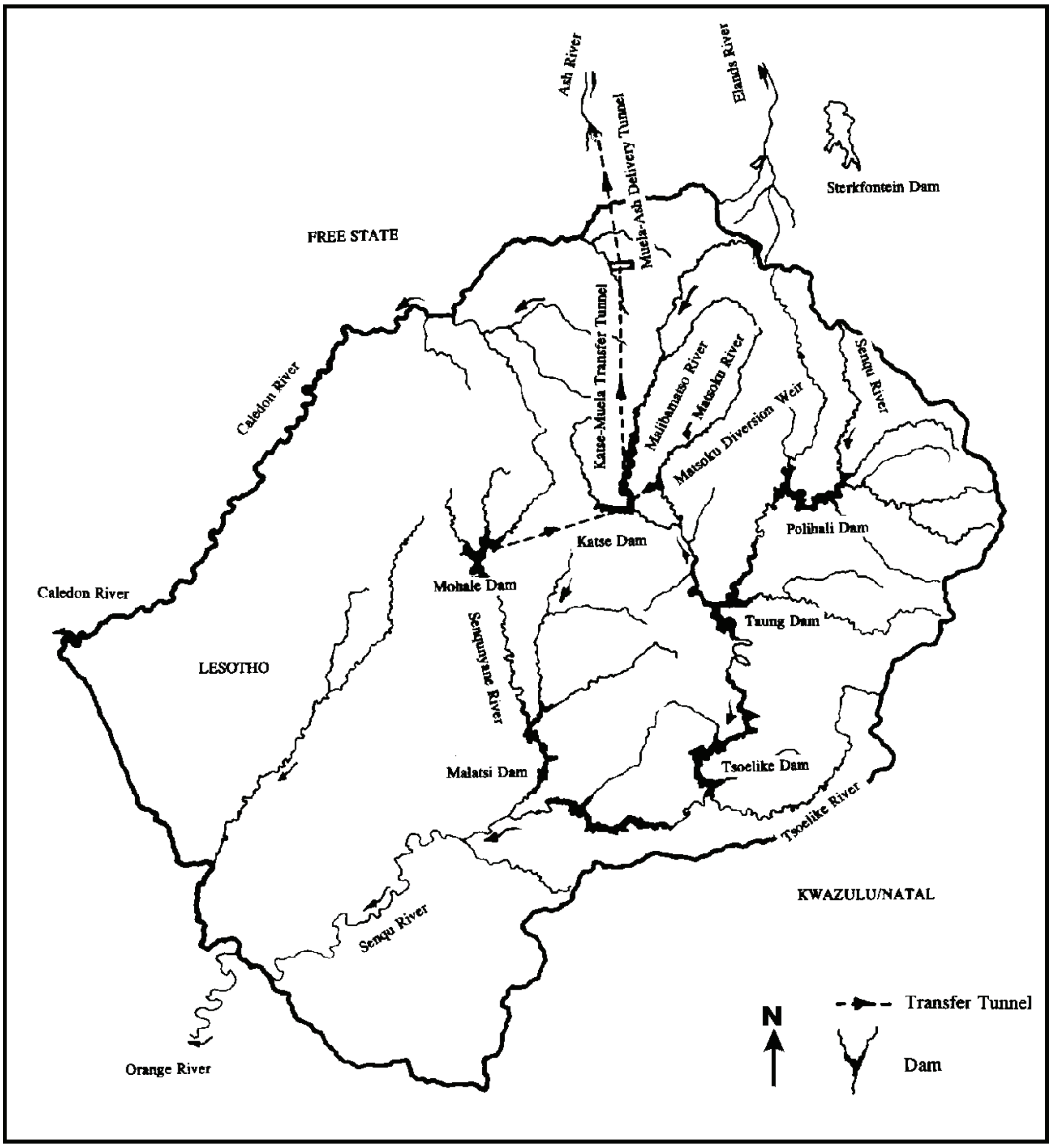


Figure 2.7 A detailed map of the first phases of the Lesotho Highlands Water Project (LHWP), which transfers water from Lesotho to South Africa (from Snaddon *et al.*, 1998).

Municipal water demands in South Africa have frequently been met by water transfers from neighbouring catchments. For example, the Caledon-Modder Scheme transfers water from the Welbedacht Dam on the Caledon River (which flows along the northern boundary of Lesotho), *via* the Knellpoort Dam on the Rietspruit, a tributary of the Caledon, to the headwaters of the Modder River which supplies water to the Bloemfontein area (Department of Water Affairs, 1989) (Scheme 18 in Figure 2.4; Table 2.4). In the Eastern Cape Province, the Amatole Scheme provides potable water to the East London/Bisho/King William's Town urban area (Scheme 8 in Figure 2.4; Table 2.4). This scheme transfers 36 x 10^6 m^3 yr^{-1} of water by gravity from the Kubusi River at Wriggleswade Dam to either the Yellowwoods River (a tributary of the Buffalo River) or the Nahoon River.

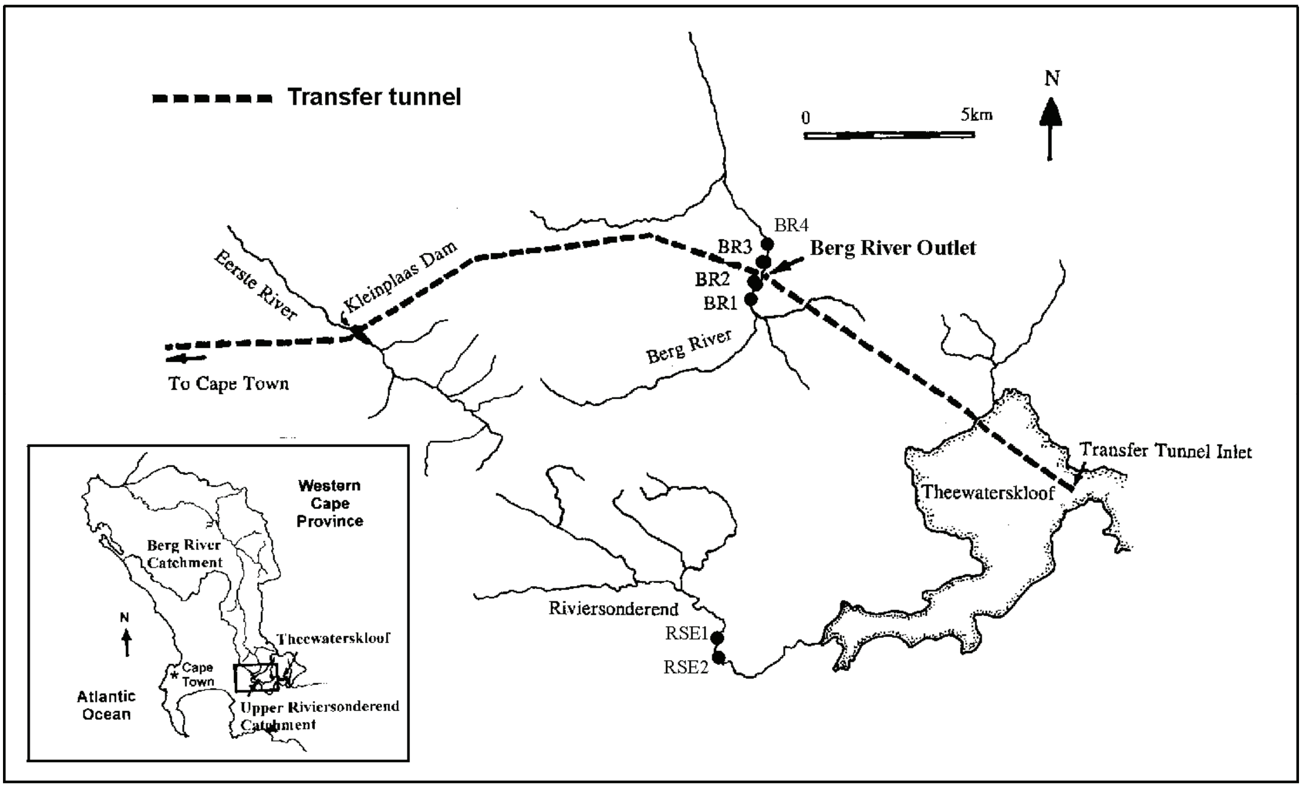


Figure 2.8 The Riviersonderend-Berg-Eerste River Government Water Scheme (RBEGS) is situated in the Western Cape Province of South Africa, and brings water to the Cape Metropolitan Area. BR1-4 and RSE1-2 indicate site codes for a research project which investigated the ecological effects of this IBT (Snaddon, 1998).

Further west, in the Western Cape Province, the Riviersonderend-Berg-Eerste River Government Water Scheme harnesses the flows from three separate river basins, those of the Riviersonderend (which flows into the Breede), Berg and Eerste rivers, and provides irrigation to the last two catchments as well as potable water supplies for the Cape Metropolitan Area (CMA) (Department of Water Affairs, 1986b) (Scheme 6 in Figure 2.4, 2.8; Table 2.4). A total of 130 x 10^6 m^3 yr^{-1} can be supplied by this scheme. As is the case for many cities around the world, more than 98% of water supplied to Cape Town is transferred from catchments well beyond its borders. Reservoirs on the Riviersonderend, Berg, Eerste and Steenbras rivers serve as donor storages for Cape Town (Table 2.5). An additional transfer scheme, the Palmiet River Scheme has recently (June 1998) augmented water supply to the CMA (Scheme 13 in Figure 2.4; Table 2.4). This last scheme will transfer winter high flows from the Kogelberg Dam on the Palmiet River, *via* the offstream Rockview Dam to the Steenbras River, and then on to Cape Town. Hydro-electric power can be generated by a pumped-storage station at Kogelberg Dam, which has a capacity of 400 megawatts. The initial quantity of water to be transferred is 22 x 10^6 m^3 yr^{-1}, but this amount was to be reviewed in 1999 (C. Bruwer, Department of Water Affairs and Forestry, personal communication, April 1998).

In 1989 the Department of Water Affairs and Forestry and the then City Council of Cape Town commissioned the Western Cape System Analysis (Ninham Shand Consulting Engineers, 1994), which was briefed to investigate the development of future water supplies in the Western Cape Province. The analysis was completed in 1994, and identified a number of IBT proposals. Four such proposals involve river systems within the Berg River catchment, over and above current impoundments in this river. The Skuifraam Dam proposal has recently received Ministerial approval (press release from Professor Kader Asmal, Minister of Water Affairs and Forestry, September, 1997). This impoundment will be built on the upper reaches of the Berg River, and will supply water to the existing Riviersonderend-Berg-Eerste River transfer scheme described above (Ninham Shand Consulting Engineers, 1997). Associated with this dam is the Skuifraam Supplement Scheme, an intra-basin transfer scheme which is designed to transfer a total of 19 x 10^6 m^3 yr^{-1} of water from the Berg River, *via* an offstream balancing dam, to the proposed Skuifraam Dam further upstream (Zille Shandler Associates, 1996) (Table 2.4). Further down the Berg River, another proposal involves the raising of the extant Misverstand Dam, in order to increase storage capacity, and to allow for the transfer of water into an existing canal (Twenty-Four Rivers canal), which presently takes water from another Berg River tributary, the Twenty-Four Rivers, to the off-channel Voëlvlei Dam (Table 2.4). Voëlvlei Dam is a major source of water for the

CMA. A proposal also exists which would involve the transfer of water from a diversion weir on the upper reaches of the neighbouring Olifants River, at the Keerom site, to the Twenty-Four Rivers canal, thus linking the Olifants and Berg River catchments. This scheme, known as the Keerom Diversion, could yield $90 \times 10^6 m^3 yr^{-1}$ (Zille Shandler Associates, 1996) (Table 2.4).

Table 2.5 Supply of water to Cape Town, giving a breakdown of the supply reservoirs, and water demand, for July 1993 to June 1996, inclusive (from Clayton, 1994, 1996).

Reservoir	**River**	**Percentage of Supply**		
		1993/4	**1994/5**	**1995/6**
Cape Town catchments:				
-	Liesbeek (Albion Springs)	-	0.1	0.3
*****Hely Hutchinson, Woodhead, De Villiers, Victoria, Alexandra	Table Mountain rivers	1.3	1.2	1.3
Catchments beyond city:				
Steenbras	Steenbras	13.7	10.4	11.5
Wemmershoek	Berg	21.5	21	20.2
Voëlvlei	Berg	25.6	25.6	22.2
Theewaterskloof	Riviersonderend	37.9	41.7	44.5

*****The total volume from these sources comprises $3.7 \times 10^6 m^3 yr^{-1}$, compared to $185.9 \times 10^6 m^3 yr^{-1}$ from catchments beyond the boundary of the City.

The Western Cape System Analysis identified three IBT proposals, all of which would affect the Breede River (Figure 2.4). The Michell's Pass Diversion would involve a transfer of water from the Breede River into the Boontjies River, a tributary of the Klein Berg which flows into the Berg River (Table 2.4). The predicted yield of this scheme is $15 \times 10^6 m^3 yr^{-1}$. The Molenaars River Diversion is proposed to transfer approximately $35 \times 10^6 m^3 yr^{-1}$ from the Molenaars River, a tributary of the Breede, either into Skuifraam Dam (Berg River), or Theewaterskloof (Riviersonderend) (Table 2.4). A further IBT has been proposed which would transfer water from Brandvlei Dam on the Breede, to Theewaterskloof Dam, which provides a large proportion of the CMA's water supply (Table 2.4, 2.5). The construction of these six IBTs would result in complex linkages between the Berg, Breede and Riviersonderend rivers, and allow for a diversity of water sources for the CMA.

Moving to the east of the country, the Durban-Pietermaritzburg metropolitan area in KwaZulu/Natal province, is one of the fastest growing urban areas in the world (Van Niekerk *et al.*, 1996). The Mooi-Mgeni Transfer Scheme currently brings water to this area when augmentation of local supplies is necessary (Scheme 9 in Figure 2.4; Table 2.4). In 1983 a maximum of $30 \times 10^6 m^3 yr^{-1}$ was delivered by the scheme, and, since then, the scheme has transferred smaller volumes during the dry summer months. Due to increased water demands, however, plans to increase transfer capacity from the Mooi have been completed, and construction will begin when the need arises (Henderson, 1995). Further transfers are planned, to augment flows in the Mgeni River, bringing water from the Mkomaas and Mzimkulu rivers. The Mkomaas-Mzimkulu-Illovo Scheme is an IBT proposal that comprises two components: one that would bring $374 \times 10^6 m^3 yr^{-1}$ from the Mkomaas to the Mgeni, and another that would transfer $305 \times 10^6 m^3 yr^{-1}$ from the Mkomaas to the Illovo River which supplies water to Durban (Scheme 14 in Figure 2.4; Table 2.4). These coastal rivers are relatively short, however, and their yields are limited.

The Richards Bay/Empangeni area is another growth node within the province. The Mhlatuze River Scheme is an intra-basin transfer scheme which has supplied water to this area for municipal and industrial use since 1984 (Van Niekerk *et al.*, 1996; Wepener and Cyrus, 1997) (Scheme 19 in Figure 2.4; Table 2.4). However, the Mhlatuze no longer meets the demands of the area, and augmentation of this source is planned from the Tugela River (Scheme 17 in Figure 2.4; Table 2.4). Thus, although KwaZulu/Natal is situated on the wetter eastern coast of South Africa, 70% of the province's production is dependent on IBTs (Figure 2.5).

Table 2.6 The mean annual precipitation (MAP) and mean annual runoff (MAR) of some major rivers of southern Africa, listed in order of decreasing catchment area. (After Conley (1995): extracted from Pitman and Hudson (1994)).

River	Area (km^2)	MAP (mm)	MAR (10^6 m^3 yr^{-1})
Congo	3 981 000	1500*	1 250 000
Zambezi	1 234 000	860	110 000
Orange	973 000	330	11 860
Kavango	586 000	580	11 650
Limpopo	413 000	520	7 330
Rovuma	155 000	1100	28 000
Cunene	117 000	830	5 550
Save	104 000	680	6 200

*Estimated MAP.

The Congo and Zambezi rivers are the only truly large perennial systems in southern Africa (Table 2.6), and both of these rivers are being investigated as potential sources of water, for countries such as Zimbabwe, Botswana and South Africa (e.g. Petitjean and Davies, 1988a; Alexander, 1996). In 1918, it was proposed that a diversion weir be built on the Zambezi in order to divert a large proportion of the flow in the river southwards to the Makgadikgadi region of central Botswana. Here it would be stored as a large inland lake, which, it was suggested, would increase rainfall over South Africa (Alexander, 1996). A more detailed proposal that arose in the 1980s included a 1200 km canal which would transfer 2500-4000 x 10^6 m^3 yr^{-1} from the Zambezi near Victoria Falls, *via* Gabarone in Botswana, to the Vaal River in South Africa (Petitjean and Davies, 1988a) (Scheme 16 in Figure 2.4; Table 2.4). Some 30% of the water would be used in Botswana. Three pump stations would be necessary along the route. It has been realised, however, that the ecological and political implications of such a scheme are prohibitive, and it will be many years before this proposal reaches anything like a feasibility assessment stage (Alexander, 1996; M. Basson, BKS Consulting, personal communication, 1998).

The Okahanja/Windhoek area in Namibia is supplied by the Eastern National Water Carrier (ENWC; Scheme 7 in Figure 2.4; Table 2.4). Windhoek is the capital of Namibia, and water shortages in the early 1980s led to the planning and construction of this IBT (Petitjean and Davies, 1988a; Davies *et al*., 1993a). The first phase of the project was completed in 1978, and comprises two dams on the Swakop River, and a pump scheme which carries the water to Windhoek (Davies *et al.*, 1992). The second phase, completed in 1983, expanded the scheme to include a dam on the Omatako River and a pump scheme transferring water at a rate of 2 m^3 s^{-1} (63 x 10^6 m^3 yr^{-1}) from the Omatako Dam to the Von Bach Dam on the Swakop. A third phase of the IBT comprises a controversial 263 km canal connecting the Karstland Borehole Scheme near Grootfontein with the Omatako Dam. A little over 200 km of this canal is open, and its capacity is 2-3 m^3 s^{-1} (63 - 95 x 10^6 m^3 yr^{-1}). The Karstland Borehole Scheme can yield 15-20 x 10^6 m^3 yr^{-1}, from 70 boreholes in the Grootfontein area (Ravenscroft *et al*., 1985). At present, water from a disused vanadium mine is also being pumped out and transferred to the canal. A final phase of the scheme, not yet built, will incorporate a 2-3 m^3 s^{-1} (63 - 95 x 10^6 m^3 yr^{-1}) transfer from the Kavango River, which feeds the Okavango swamps in Botswana, into the Grootfontein-Omatako canal (Davies *et al*., 1992). This last phase of the project has met with substantial opposition from the communities living in the Okavango Delta area, as abstraction from the river would threaten the Delta ecosystem, and thus their livelihoods which depend on the fish and water in the system.

Construction has recently commenced on a North-South Water Carrier in Botswana. This scheme will transfer water from the northern Shashe River, *via* a 360 km pipeline to towns and cities along the eastern border of Botswana, including the capital city of Gabarone (*The Herald*, 8 February, 1998; Omari *et al*., 1998).

2.2. Continental America

2.2.1 Canada

The MAR for Canada is approximately 3300 x 10^9 m^3, which is equal to 9% of the world's streamflow. Groundwater and lakes augment the fairly plentiful freshwater resources of the country (Sewell, 1967). Water resources development is thus seldom motivated by water supply requirements, but rather for energy generation: 96% of all Canadian water transfers can be attributed to hydro-electric power generation, which produces 70% of Canada's electrical energy. IBTs have been constructed on a large scale in Canada and the total amount of water transferred throughout Canada is 14 x 10^9 m^3 yr^{-1}, equivalent to a substantial human-made river (Quinn, 1981).

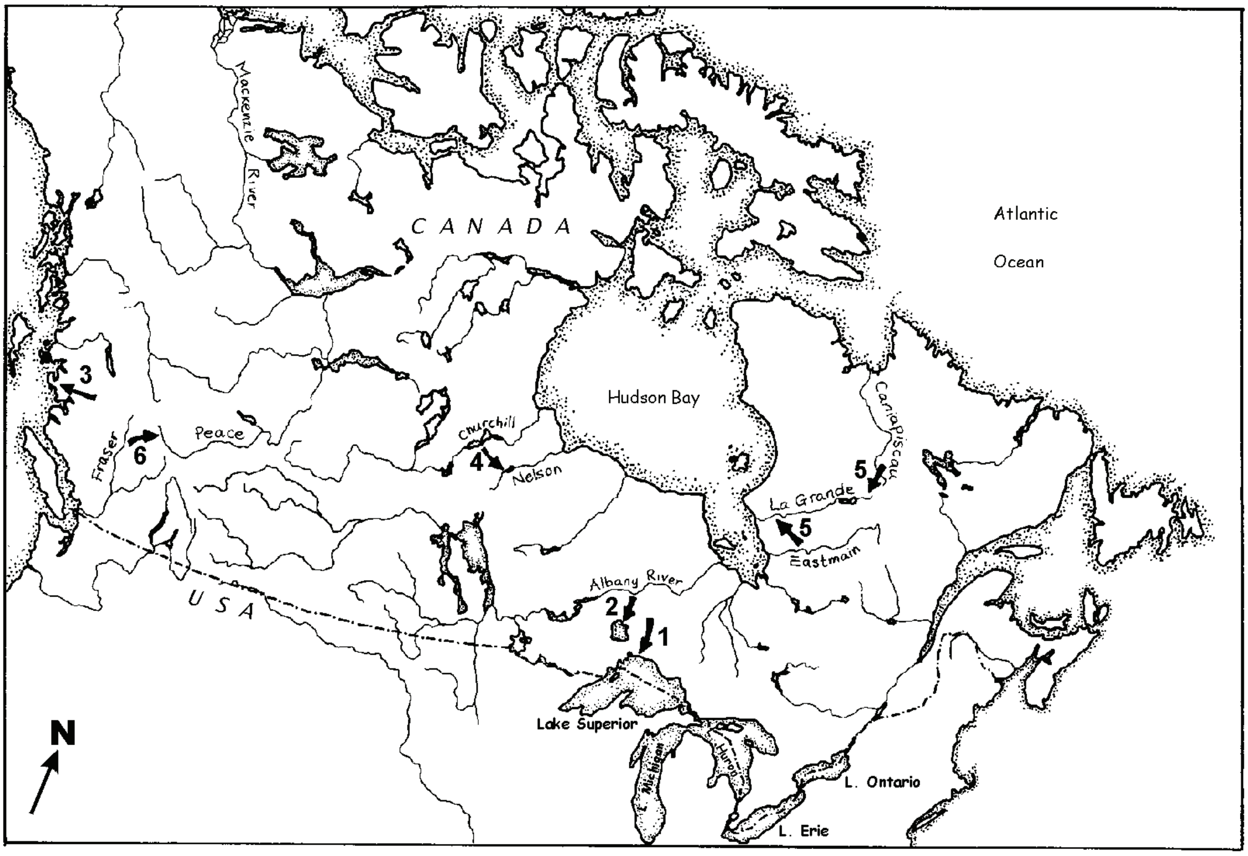


Figure 2.9 Some of the major IBT schemes in Canada, as described in the text. 1, Long Lake Diversion; 2, Ogoki Diversion; 3, Kemano Diversion; 4, Churchill River Diversion; 5, James Bay Project; 6, McGregor Diversion.

In a report on an inquiry into federal Water Policy dealing with Canadian IBTs, Day (1985) provided an overview of the status of Canadian schemes, and focused on five transfers - the Long Lake and Ogoki, Kemano, and Churchill River diversions, and the James Bay Project (Figure 2.9; Table 2.7). The Long Lake Diversion was completed in 1939, and transfers water southwards from the Kenogami River, through Long Lake, to the Aguasabon River, which flows into Lake Superior. The Ogoki Diversions came into operation in 1943, and diverts water from the Ogoki River into the Little Jackfish River, which flows into Lake Nipigon. Both schemes provide the dual functions of inter-basin pulpwood transport, and hydro-electric power generation. The Kemano Diversion consists of the diversion of an annual average of 115 m^3 s^{-1} (3.6 x 10^9 m^3 yr^{-1}) from the Nechako River to a hydro-electric power plant at Kemano, from where the water is released to the Kemano River and then into the Pacific Ocean. Its sole use is hydro-electric power generation.

The Churchill River Diversion was commissioned in 1976, also for hydro-electric power generation (Day, 1985). Southern Indian Lake on the Churchill River is dammed at its northern outlet and water is diverted from the Lake's southern basin into the Rat River, from where it flows into the Burntwood and Nelson rivers, eventually passing *via* the Kettle and Long Spruce generating stations to Hudson Bay. The Rat River receives an average diverted annual flow of 775 $m^3 s^{-1}$ (24 x 10^9 $m^3 yr^{-1}$), while to the south, Lake Winnipeg was transformed into a reservoir by construction of a hydro-electric power unit at Jenpeg, through which 2016 $m^3 s^{-1}$ (63 x 10^9 $m^3 yr^{-1}$) flows into the Nelson River. The James Bay Project is another hydro-electric power development (Day, 1985), where flows in the Eastmain and Caniapiscau rivers are transferred into the La Grande Rivière. A third transfer brings water from the Sakami River in a neighbouring catchment, *via* a hydro-electric power generation unit. The total amount transferred to the La Grande almost doubles its natural discharge.

A further Canadian IBT proposal, the McGregor diversion, would have transferred 6.3 x 10^6 $m^3 yr^{-1}$ from the headwaters of the Fraser River to the headwaters of the Peace River in northern British Columbia, in order to reduce flood flows and increase hydro-electric power generation (Figure 2.9; Table 2.7). This proposal was shelved in 1978, however, as a result of possible impacts on the ecosystems concerned (Day, 1985).

The North American Water and Power Alliance, NAWAPA, which was first suggested in the mid-1960s, was an ambitious plan aimed at transferring water from north-western North America to other areas of Canada, the United States and Mexico (e.g. Micklin, 1977). The cost of the project was estimated at U$120 billion (at 1976 prices). The original transfer of 136 x 10^9 $m^3 yr^{-1}$ of water was to be apportioned between the United States (61%), Canada (20%) and Mexico (19%), with a potential increase to 308 x 10^9 $m^3 yr^{-1}$. The purposes of the scheme were multiple: expanded irrigation (enough to irrigate a total of 22 x 10^6 ha), increased hydro-electric power production (100 000MW of which 70% would be available for industrial and domestic use), the development of a navigable network of canals (of which the Canadian Great Lakes Waterway is the most substantial, allowing ocean-going vessels access to the interior of the country), flood and pollution control, municipal water supply and recreation. NAWAPA was shelved due to the numerous vocal and politically active public organisations (Sewell, 1967; Micklin, 1977), but remains as a proposal.

Table 2.7 A list of current and proposed Canadian IBT schemes.

Scheme	Purpose	Donor	Recipient	Annual Volume Transferred (10^6 $m^3 yr^{-1}$)	Average Transfer Rate ($m^3 s^{-1}$)
Long Lake Diversion	pulpwood transport, hydro-electric power	Kenogami	Aguasabon	1356	42.5
Ogoki Diversion	hydro-electric power	Ogoki	Little Jackfish	3563	113.25
Kemano Diversion	hydro-electric power	Nechako	Kemano	3626	115
Churchill River Diversion	hydro-electric power	Churchill	Rat, Burntwood and Nelson	24 440	775
James Bay Project	hydro-electric power	Eastmain Caniapiscau and Sakami	La Grande	50 457	1586
Proposed:					
McGregor Diversion	reduce flooding, hydro-electric power	Fraser	Peace	6.3	-
North American Water and Power Alliance	multi-purpose	Various	Various	136 000	-

2.2.2 The United States of America and Mexico

The United States of America (U.S.A) has vast water resources. The annual renewable water supply of the conterminous U.S.A. amounts to about 1900 x $10^9 m^3$ (Foxworthy and Moody, 1986). However, the Nation's water resources are not evenly distributed, particularly between the eastern and western parts of the country. The eastern U.S.A. is generally humid and receives a mean annual precipitation (MAP) in excess of 1000 mm yr^{-1} (Figure 2.10). Areas of the U.S.A. that have relatively large amounts of precipitation generally have relatively large amounts of runoff. The MAR for the eastern U.S.A. ranges from about 250 mm yr^{-1} along the Mississippi River to greater than 1000 mm yr^{-1} in the mountains to the east (Foxworthy and Moody, 1986).

Unlike the eastern U.S.A., the western U.S.A., with the exception of the Pacific Northwest, is arid to semi-arid, with a MAP of less than 500 mm yr^{-1} (Figure 2.10). In addition to low rainfall, much of the area (away from mountain ranges) has a MAR of only 30 mm yr^{-1} or less (Foxworthy and Moody, 1986). The United States Water Resources Council (1978) established 21 water-resources regions in the U.S.A., 18 in the conterminous U.S.A. (Figure 2.11) and one each for Alaska, Hawaii, and the Caribbean. Each region represents a natural basin or hydrological area that contains the drainage area of a major river or the combined drainage areas of two or more rivers. Annual renewable supplies range from 6.9 x $10^9 m^3 yr^{-1}$ in the Rio Grande to 64.9 x $10^9 m^3 yr^{-1}$ in the Lower Mississippi (Table 2.8).

The eastern U.S.A. contains the majority of the country's population and industrial activity. Coincidentally, the New England, Mid-Atlantic, South Atlantic-Gulf, Great Lakes, Ohio, Tennessee and Upper Mississippi water-resources regions had urban water use values in excess of 90% of total water use in 1990. Conversely, in the western U.S.A., the Rio Grande, Upper and Lower Colorado, Great Basin, and the Pacific Northwest water-resources regions had irrigation-use values in 1990 that were greater than 75% of total water use for each region. If these comparisons of urban and irrigation water uses remain unchanged, increasing water demands in the eastern U.S.A. are likely to focus on meeting increasing population and industrial demands, whereas water demands in the western U.S.A. are likely to focus on water availability to meet agricultural needs and a growing population.

One measure of the degree to which available water resources of any region have been developed is the percentage of annual renewable supply that is used consumptively. Data from 1980 suggest that the percentage use of renewable supply ranged from about 1% in the New England and Tennessee regions to almost 100% in the Lower Colorado region (Table 2.8). Although regional estimates may not represent local conditions, overall water use in the U.S.A. is a relatively small percentage of supply, particularly in the eastern U.S.A. In the western U.S.A., relatively high percentages of renewable supplies are consumptively used, indicating that additional consumptive use will be constrained by water availability. The eastern U.S.A. may not have the plentiful water resources that are assumed to be available, given the declining quality of existing water supplies (Sherk, 1994). Thus, water transfers have been sought throughout the country as one means of increasing water supply.

The practice of diverting water from an area of perceived surplus to areas where water supply demands are increasing, has been used for many years in the U.S.A. Indigenous Americans in central Arizona constructed over 2000 km of canals in what is now the metropolitan Phoenix area (Marsh and Minckley, 1982). Although more like irrigation canals and not IBTs in the strict sense, these canals, as well as "*acequias*" designed by Spaniards in the south-western U.S.A. during the 1600s and 1700s, served as an important precedent in the development of large-scale transfer projects that followed in this region (Warnick, 1969). Petsch (1985) has reported a total of 111 water transfers between water-resource subregions in the western U.S.A.

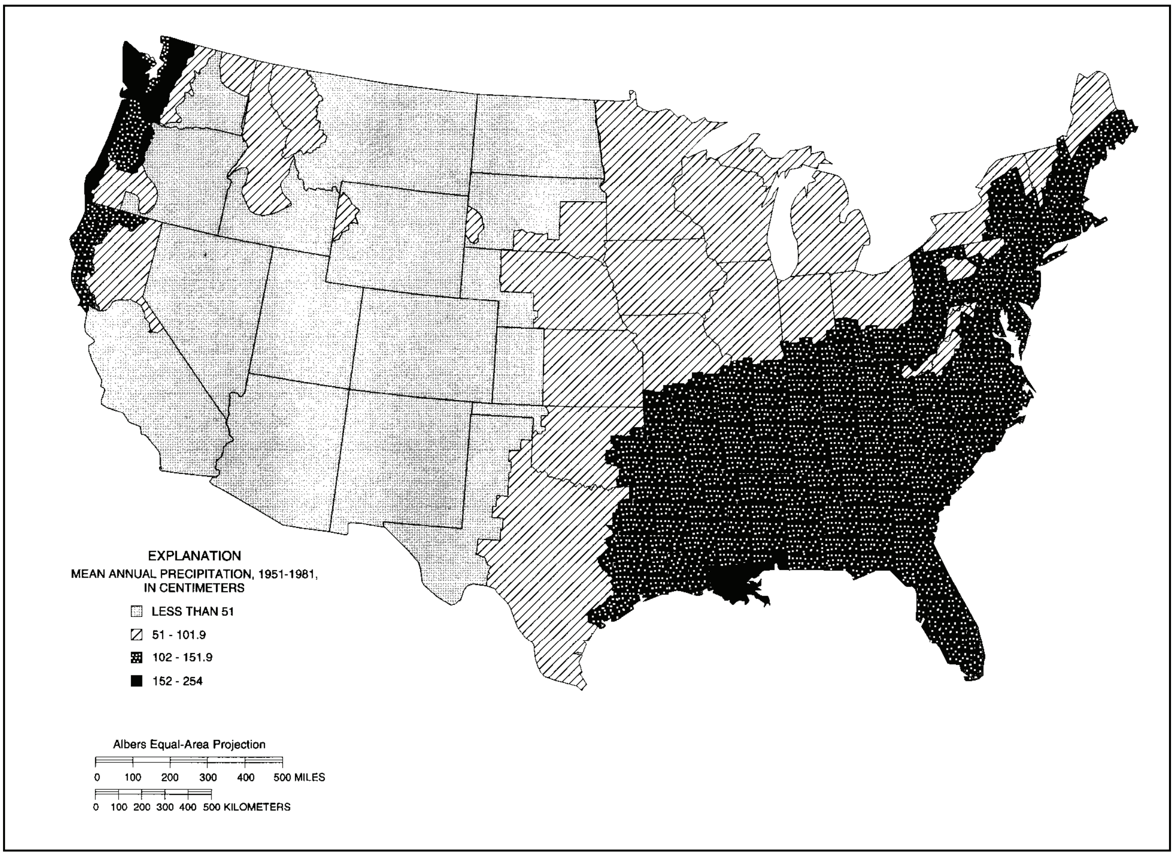


Figure 2.10 Mean annual precipitation of the conterminous United States. Data are from Foxworthy and Moody (1986).

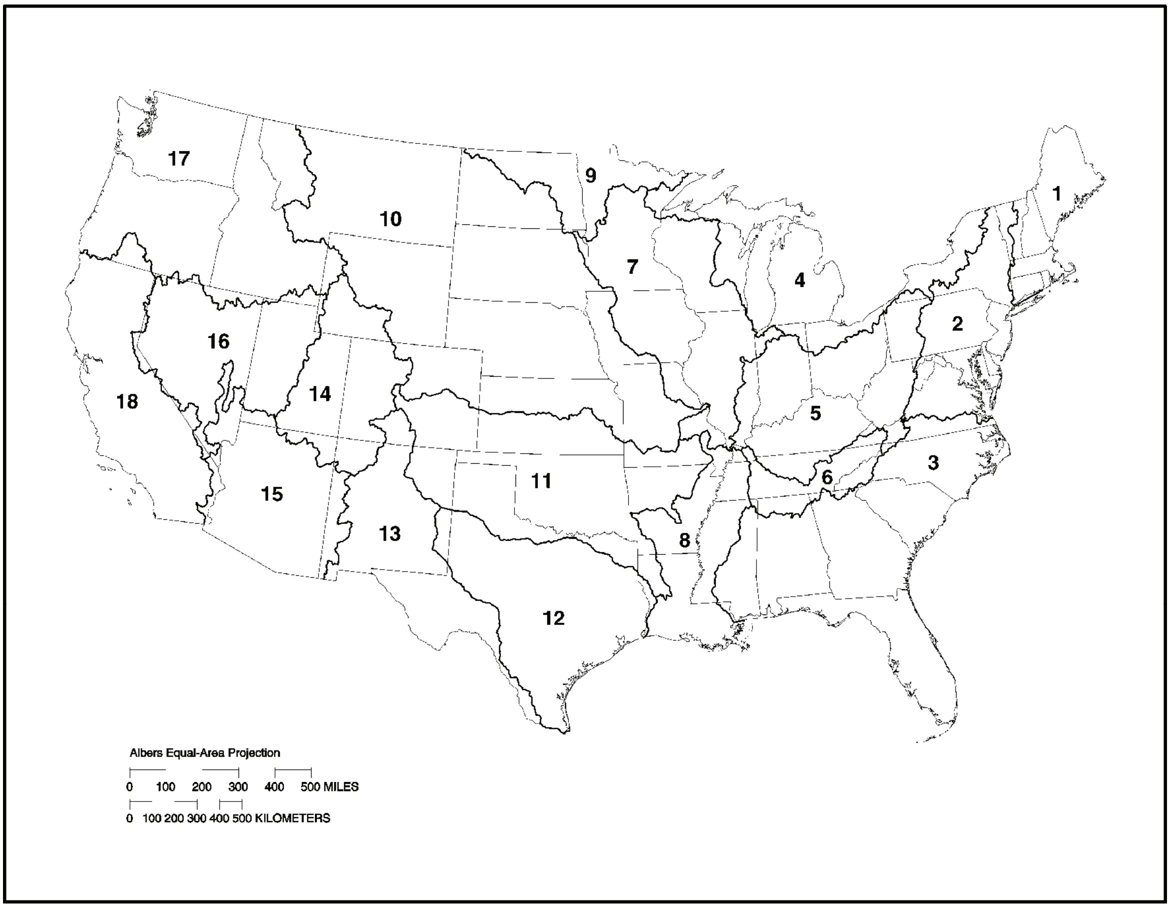


Figure 2.11 Water-resources regions of the conterminous United States.

Table 2.8 Annual renewable supply in 10^6 m^3 yr^{-1} and percent of annual renewable supply consumptively used in 1985 for water-resources regions of the conterminous United States of America. Data are taken from Foxworthy and Moody (1986).

Water-resources region	Annual renewable supply	% of renewable supply consumptively used
East		
1 New England	106 800	0.8
2 Mid-Atlantic	133 300	2.0
3 South Atlantic-Gulf	294 300	2.6
4 Great Lakes	106 100	2.1
5 Ohio	193 400	1.5
6 Tennessee	59 800	0.9
7 Upper Mississippi	110 100	2.6
8 Lower Mississippi	649 300	9.0
Total	1 653 100	
West		
9 Souris-Red-Rainy	10 600	6.5
10 Missouri Basin	93 000	29.0
11 Arkansas-White-Red	88 000	17.0
12 Texas-Gulf	49 600	23.0
13 Rio Grande	6 900	64.0
14 Upper Colorado	17 000	33.0
15 Lower Colorado	15 500	96.0
16 Great Basin	11 500	49.0
17 Pacific Northwest	402 000	4.3
18 California	120 100	29.0
Total	814 200	
Grand total	2 467 300	

California was the first State in the U.S.A. to develop an IBT to meet regional demands. California has a keen interest in inter-basin transfer because most of the State's potentially usable water is located in the northern third of the State, whereas most of the water demand is located in the semi-arid southern two thirds. Proposals to transfer water from the Sacramento Valley to the San Joaquin Valley began as early as 1873 (Howe and Easter, 1971). The first California Project to be constructed, the Los Angeles Aqueduct, was completed in 1913 to transfer water from Owens Valley on the eastern slopes of the Sierra Nevada Mountains to the city of Los Angeles (Figure 2.12; Table 2.9). In 1928, a 389 km aqueduct was constructed to transfer water from the Colorado River to the metropolitan Los Angeles area (Reisner, 1986) (Figure 2.12; Table 2.9). The agriculturally rich Central Valley Basin of California has been supplied with water from the northern Trinity River since the mid-1960s. The Central Valley Project transfers water from the Trinity, *via* the Clear Creek Tunnel with a maximum transfer capacity of 105 m^3 s^{-1} (3 x 10^9 m^3 yr^{-1}), to the Sacramento River (Figure 2.12; Table 2.9), for irrigation, hydro-electric power generation, recreation and conservation (United States Bureau of Reclamation, 1980, 1983). One of the most complex and expensive IBTs was created by the construction of the California State Water Project in 1972. Designed to transfer water from northern California's Feather River to southern California, the project included 21 dams and reservoirs, 22 pumping plants, and 1100 km of canals, tunnels, and pipelines (Figure 2.12; Table 2.9).

Table 2.9 IBT schemes in North America and Mexico

Country	State	Scheme	Purpose	Donor	Recipient	Annual Volume Transferred (10^6 m^3 yr^{-1})	Average Transfer Rate (m^3 s^{-1})
U.S.A.	**California**	Los Angeles Aqueduct	general supply	Owens Lake	Los Angeles metropolitan area		
U.S.A.	**California**	-	general supply	Colorado	Los Angeles metropolitan area	580	-
U.S.A.	**California**	Central Valley Project	general supply	Trinity	Sacramento	3300	105 (maximum)
U.S.A.	**California**	California State Water Project	general supply	Sacramento and Feather	Southern California	5210	-
U.S.A.	**Nevada**	Truckee Canal	irrigation	Truckee	Carson	-	-
U.S.A.	**Colorado**	Big Thompson Project	irrigation and municipal supply	Colorado	Platte	370	-
U.S.A.	**Colorado**	Frying Pan-Arkansas Project	irrigation	Colorado	Arkansas	-	-
U.S.A.	**Arizona**	Central Arizona Project	irrigation	Colorado	Gila	2650	84 (maximum)
U.S.A.	**New Mexico**	San Juan-Chama Transfer	irrigation and general supply	Colorado	Rio Grande	-	-
U.S.A.	**Texas**	Canadian River Project	municipal and industrial use	Canadian	Red, Brazos and Colorado	190	-
U.S.A.	**Texas/ Oklahoma**	Lake Texoma-Lake Lavon Transfer	supply to Dallas	Red	Trinity	-	-
U.S.A.	**New York**	New York supply	municipal supply	Delaware	New York City	-	-
U.S.A.	**Virginia**	Virginia Beach supply	municipal supply	Roanoke	Virginia coast	83	-
U.S.A.	**S. Carolina**	Santee-Cooper Project	hydro-electric power	Santee	Cooper	-	-
U.S.A.	**S. Carolina**	Santee-Cooper Re-Diversion Project	dilution of sediment	Cooper	Santee	-	-
Mexico	-	National Water Plan	municipal supply	Groundwater in the Lerma Basin, Cutzamala and Amacuzac rivers	Mexico City	1700	54
Mexico	-	Water Plan for the Noroeste Region	multi-purpose	Rivers of Sinaloa State	Alamos River	-	-
Proposed:							
U.S.A.	**Texas**	Texas Water Plan	irrigation	Mississippi, Arkansas and White	Texas High Plains	-	-
North America	-	Grand Replenishment and Northern Development Canal	hydro-electric power and flood control	James Bay Basin	Great Lakes, Canada	-	-
North America	-	Garrison Diversion Project	multi-purpose	Missouri	Various, including Lake Winnipeg, Canada	-	-
North America	-	-	drought relief	Great Lakes, Canada	Mississippi and Illinois	8830	280
Mexico	-	National Water Plan	municipal supply	Tecolutla and Oriental	Mexico City	-	-

In 1905, the Truckee River in western Nevada was diverted into the Carson River by way of the Truckee Canal (Figure 2.12; Table 2.9). The initial diversion was promoted because agricultural development was believed to be the key to the State's future (National Research Council, 1993). However, as Nevada's agricultural base declines and urbanisation increases, the need for increased water supplies continues despite changing land and water use. Settlers in the late 19th century realised that for agriculture to expand on the Great Plains, water from the western slopes of the Rocky Mountains had to be diverted to the drier eastern plains. What followed was the construction of a series of tunnels, including the Moffet, Vasquez, Gumlick, and Roberts tunnels, which were designed to transfer water eastwards through the Rocky Mountains. These transfers included the Big Thompson Project in north-central Colorado that transferred water from the Colorado River to the Platte River Basin, and the Frying Pan-Arkansas Project that diverted water from the Colorado River Basin into the Arkansas River Basin (Figure 2.12; Table 2.9). Another major IBT from the Colorado River Basin is the Central Arizona Project (CAP) in southern Arizona (Figure 2.12; Table 2.9). This major IBT supplies water to the desert cities of Phoenix and Tucson, carrying water between the Colorado and Gila rivers. The major transfer structure (an open canal and tunnel combination) is designed for a maximum flow of 84 $m^3 s^{-1}$ (2.6 x 10^9 $m^3 yr^{-1}$) (Yeh *et al*., 1980). Water also has been diverted from the Colorado River Basin into the Rio Grande River Basin by way of the San Juan-Chama rivers in northern New Mexico (Figure 2.12; Table 2.9). IBTs have been a significant feature of water resources development in the Colorado River basin over the last few decades. In the 1970s, over half the population of the western U.S.A. was dependent on water from the Colorado (Stamm, 1975).

Texas has also been active in constructing IBTs. In 1950, Texas, New Mexico and Oklahoma entered into the Canadian River Compact, and an IBT known as the Canadian River Project was approved as a federal reclamation project (Templer and Urban, 1995) (Figure 2.12; Table 2.9). The Canadian River originates in New Mexico, and flows for 288 km across the Texas Panhandle before joining the Arkansas River in Oklahoma. In 1956, the authority responsible for water allocations from the project received a permit from the Texas Legislature to appropriate more than 127 x 10^6 $m^3 yr^{-1}$ of water for municipal purposes and 63 x 10^6 $m^3 yr^{-1}$ for industrial use. The Canadian River Project transfers waters from the Canadian River into the Red, Brazos and Colorado River basins, and is one of the oldest and longest IBTs in Texas. The project is unique as it provides water for municipal and industrial uses, unlike most Bureau of Reclamation efforts to enhance water supplies solely for irrigation. Proposals have also been made to divert water to the Texas High Plains and New Mexico from the Mississippi River (e.g. Watts and Laneur, 1969; Burleigh, 1970; Greer, 1983), and from the Arkansas and White rivers in Arkansas (the Texas Water Plan; Figure 2.12). However, recent evaluations of cost and water demands in the basins of origin appear to make inter-basin transfer of water to the Texas High Plains unlikely in the near future (Lacewell and Lee, 1988). A smaller scale IBT was completed in 1988 to provide water to the area of metropolitan Dallas. Water was pumped from Lake Texoma (Oklahoma-Texas Red River Basin) to Lake Lavon (Texas, Trinity River Basin) using a combination of existing stream channel and pipeline (Schorr *et al*., 1993) (Figure 2.12; Table 2.9).

Water transfers in the U.S.A. have not been limited to the west. To support the population of metropolitan New York, water has been diverted from the Delaware River Basin (Howe and Easter, 1971) (Figure 2.13; Table 2.9). IBTs also have been proposed for Florida (Massarelli and Hannah, 1983) and Connecticut (Fattarusso, 1982). In Virginia, the City of Virginia Beach is constructing a pipeline to transfer 83 x 10^6 $m^3 yr^{-1}$ of water from Lake Gaston (North Carolina-Virginia), in the Roanoke River Basin to the coast of Virginia (Cox and Shabman, 1982) (Figure 2.13; Table 2.9). In South Carolina, water has been transferred between the Santee and Cooper River basins. In 1942, the Santee-Cooper Project was constructed to divert Santee River water into the Cooper River for hydro-electric power generation (Figure 2.13; Table 2.9). However, environmental impacts such as an increased sediment load in the Cooper River, necessitated the Santee-Cooper Re-diversion Project in 1985 to redivert flow from the Cooper River to the Santee River. Mooty and Jeffcoat (1986) reported a total of 145 conveyances that transfer water between water-resource subregions in the eastern U.S.A.

IBTs across international boundaries also have been considered by the U.S.A. The concept of the Grand Replenishment and Northern Development Canal involves the collection and diversion of runoff from the James Bay watershed in Canada into the Great Lakes for water-level control and hydro-electric power production. A proposal was also put forward to divert water from the Great Lakes in Canada to the Mississippi and Illinois rivers, which flow through drought-stricken areas (Dayton, 1988). The proposal comprised a 280 $m^3 s^{-1}$ (9 x 10^9 $m^3 yr^{-1}$) diversion from Lake Michigan through the Chicago Sanitary and Ship Canal, and into the Illinois River, which flows into the Mississippi. Perhaps the largest IBT ever devised is the North American

Water and Power Alliance (NAWAPA), referred to in Section 2.2.1. The project would provide water to 7 Canadian provinces, 33 states in the U.S.A., and 3 states in Mexico. With one exception, the complexities of such projects have thus far prevented construction.

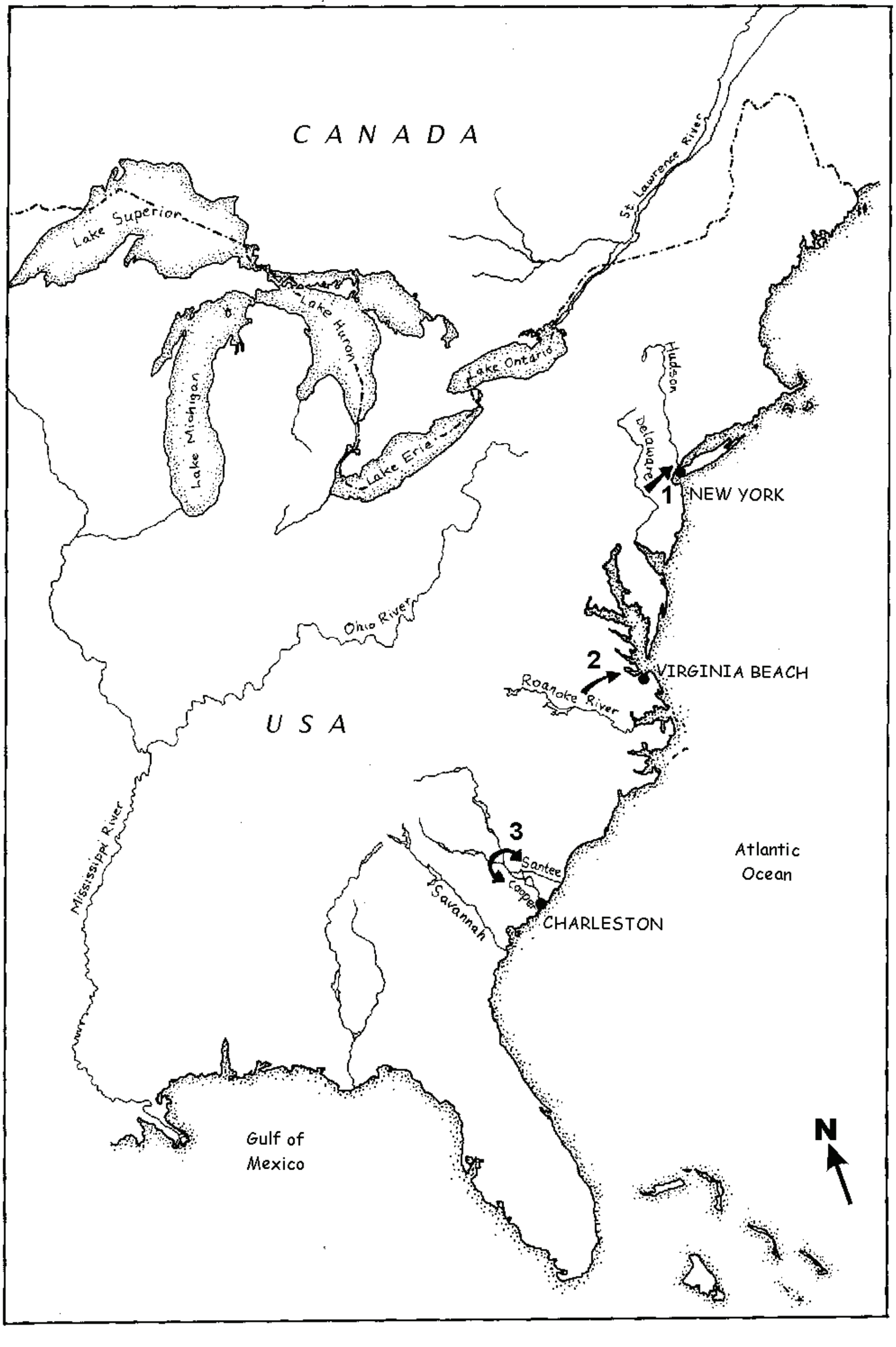


Figure 2.13 The IBT schemes of the eastern U.S.A. 1, New York supply; 2, Virginia Beach supply; 3, Santee-Cooper Diversion and re-Diversion Project.

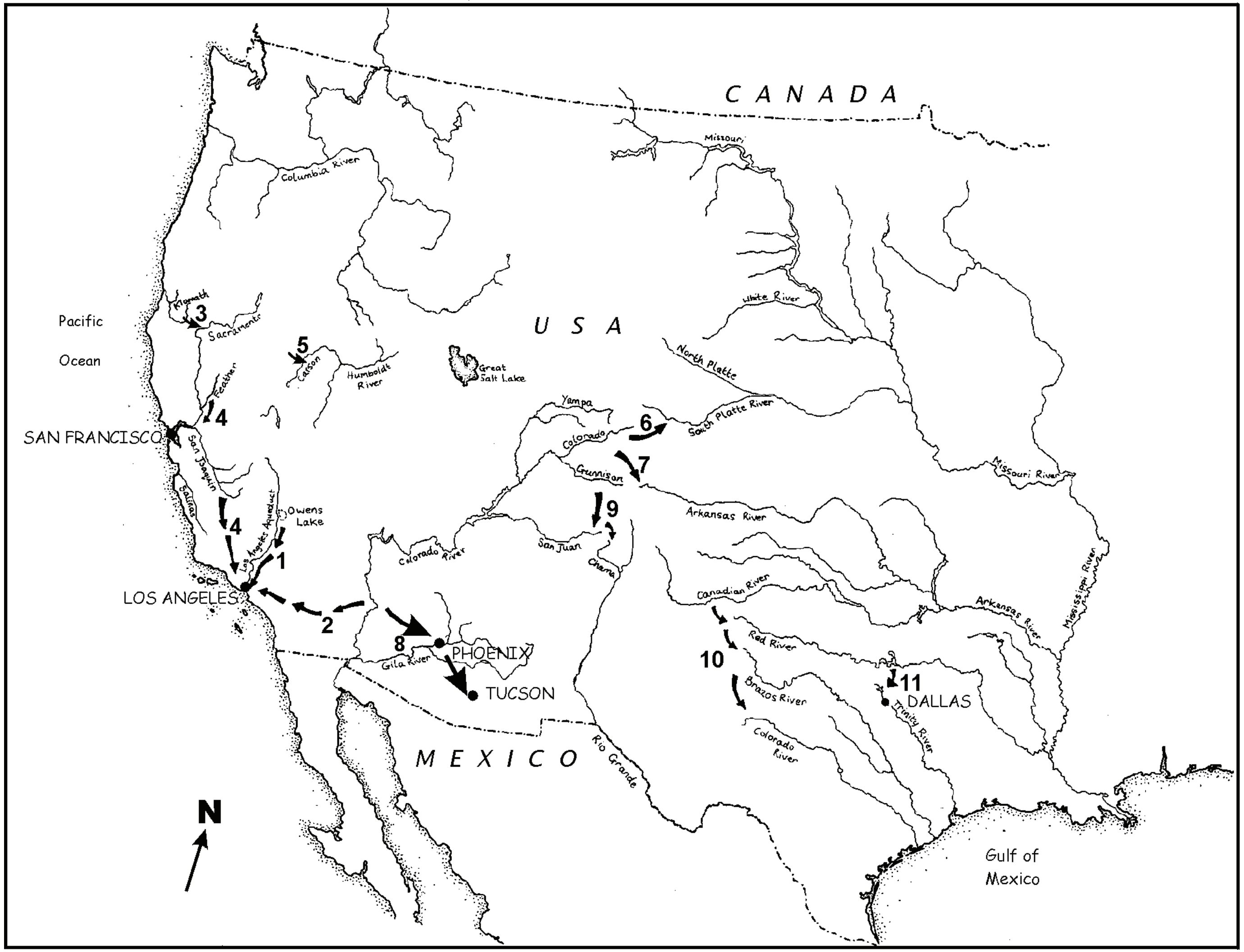


Figure 2.12 A map of the IBT schemes of the western and central United States of America (U.S.A.), which are described in the text. 1, Los Angeles Aqueduct; 2, Colorado-Los Angeles Transfer; 3, Central Valley Project; 4, California State Water Project; 5, Truckee Canal; 6, Big Thompson Project; 7, Frying Pan-Arkansas Project; 8, Central Arizona Project; 9, San Juan-Chama Transfer; 10, Canadian River Project; 11, Lake Texoma-Lake LavonTransfer.

The exception is a prominent international water-transfer project, the Garrison Diversion Project in North Dakota. Originally authorised in 1965, this scheme was one of the largest and most expensive public works projects ever undertaken in the U.S.A. (Keys, 1984). The original plan was for the diversion of water from the Missouri River in North Dakota to provide irrigation for agriculture along the transfer route. In its original form, the project would have conveyed water to irrigation areas in northern North Dakota through a canal system about 4740 km long, with return flows to Lake Winnipeg in Canada. In 1986, the U.S.A. government scaled it down, because of environmental concerns, and shifted the focus away from irrigation towards municipal, fish and wildlife, and recreational uses. Although construction has been completed, controversies over the project continue and its future is unclear.

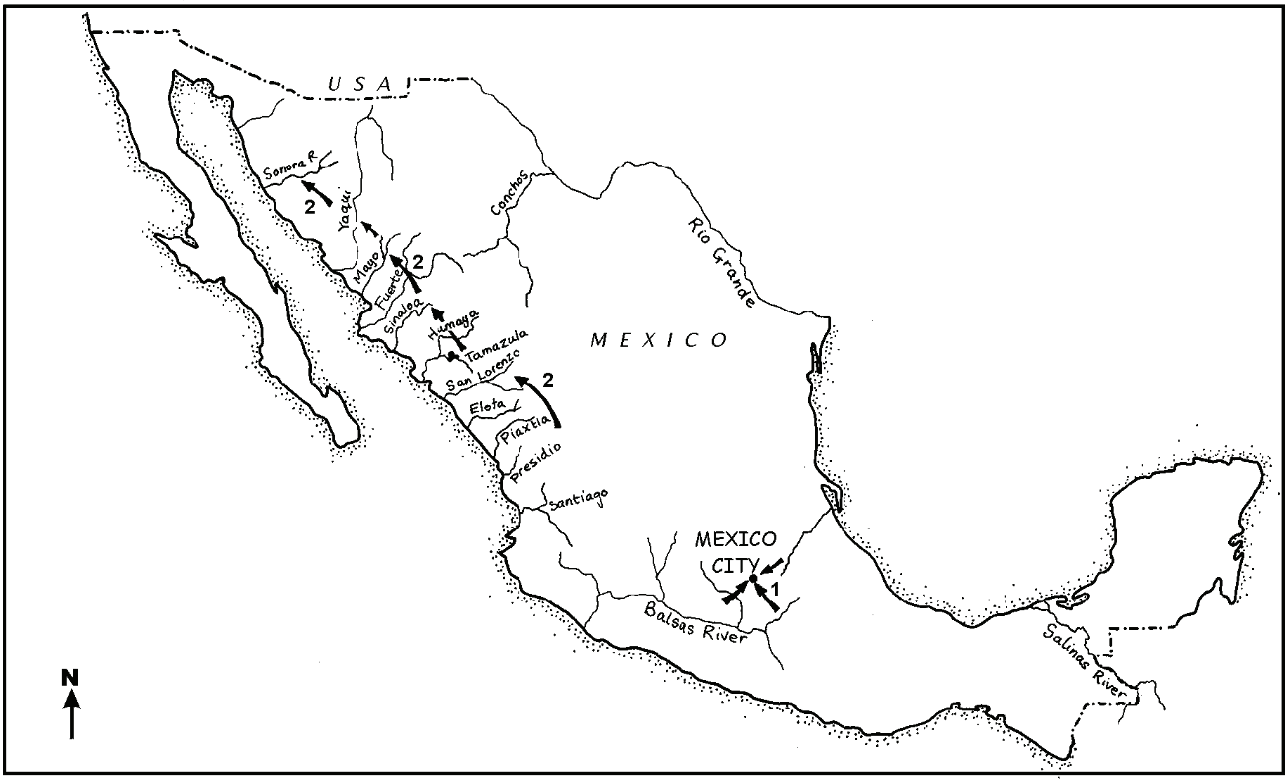


Figure 2.14 A map showing the location of the major IBT schemes in Mexico. 1, National Water Plan; 2, Water Plan for the Noroeste Region.

Further south, Mexico receives a MAP of 864 mm, and roughly a quarter of this is converted to runoff (Garduño, 1985). As is often the case, water is unevenly distributed throughout the country, with a MAP of 144 mm in the north-west of the country (Baja California), and 2763 mm in the south (Grijalva-Usumacinta region). Water transfers between regions have become necessary in order to meet water demands in the country. In the first half of this century, irrigation requirements accounted for most of the water consumed. Agricultural consumption currently accounts for approximately 95% of water use, but this proportion is expected to decrease as water demands for hydro-electric power generation increase (Garduño, 1985). The major agricultural region in Mexico is the Noroeste Region, which receives a MAP of 747 mm. The southern parts of this region are wetter, with a MAP of 1300 mm, compared to 200 mm in the north (Garduño, 1985). The Water Plan for the Noroeste Region (“Plan Hidraulico del Noroeste” (PLHINO)) was an IBT proposal initiated in the 1950s to transfer water from the south to the north, in order to facilitate the irrigation of more land, and to alleviate pressures on groundwater supplies in the north (Cummings, 1974; Garduño *et al.*, 1978; Garduño, 1985). The first stage of the PLHINO is an integrated and complex plan, for water supply, agriculture, industry, hydro-electric power generation, aquaculture development and flood control. As yet uninitiated, it would connect ten river basins (Fuerte, Sinaloa, Mocorito, Humaya, Tamazula, San Lorenzo, Elota, Piaxtla, Quelite and Presidio) in the southern Sinaloa region, with the Sonora River in the northern Sonora region (Figure 2.14; Table 2.9). The scheme would involve numerous hydro-electric power stations, pumping stations and dams.

A second IBT, which is located near Mexico City, is the National Water Plan (NWP) (Cummings, 1974; Garduño *et al*., 1978; Garduño, 1985) (Figure 2.14; Table 2.9). In terms of municipal water supply, water demand in Mexico City is high, and increasing. Mexico City was built in 1325 on a plain in a closed valley, surrounded by lakes. The city has had a history of flooding, and by the late 1700s it was necessary to build a trench which carried excess water out of the valley into the neighbouring Tula Basin. The drilling of wells for water supply in the urban areas caused subsidence and alterations to the sewage system, which then caused further flooding. A second artificial outlet was then built at the beginning of this century. In terms of water supply, water resources within the Valley of Mexico were adequate for human needs, until the middle of the 20th century. In order to meet growing demands for water, the first transfer of groundwater from the neighbouring Lerma Basin was completed in 1958. A second transfer was built later, transferring 4m^3 s^{-1} of surface water from the Cutzamala and Amacuzac rivers in the Balsas River basin in the west (Garduño, 1985). By the year 2000, the water system will provide Mexico city with 109 m^3 s^{-1} of transfer flow, possibly bringing water from the Tecolutla and Oriental River basins.

2.2.3 South America

Few references were found with information on IBTs in South America. One of these dealt with an IBT in south-eastern Brazil. This area has a fairly unusual topography, which is dominated by an inland plateau that runs parallel to the Atlantic coast for approximately 2000 km, and ranging in height from 300 to 800 mAMSL. The plateau tilts away from the coast, and thus streams arising in this area flow inland, and into larger rivers that discharge to the north or south of the plateau (*Water Power*, 1953). The Lajes River is an exception to this, discharging on the coastal side of the plateau. In 1913, a dam was built on the neighbouring Piraí River, and water was diverted to the Lajes River by gravity through an 8 km tunnel. The purpose of this transfer was for hydro-electric power generation. By the 1950s, however, demands for hydro-electric power exceeded the capacity of this IBT, and the Paraíba-Piraí transfer was proposed and constructed. The Piraí is a tributary of the Paraíba River. The IBT comprises a diversion from the Paraíba, through a tunnel and open canal to the Santana Reservoir on the Piraí River, and then on to the Lajes River (Figure 2.15; Table 2.10). The capacity of the transfer is 160 m^3 s^{-1} (5 x 10^9 m^3 yr^{-1}) (*Water Power*, 1953).

An additional IBT proposal in South America would bring water to Lima, the capital of Peru (Andrews, 1983). This city has been supplied with water from the River Rimac, which has seasonal and unpredictable flow. Furthermore, in the early 1980s, water demands in the city were no longer being met by this supply. Since 1968 exploratory work has been carried out on the Mantaro transfer project. Water would be pumped from the River Mantaro, across the Continental Divide, and released into the River Rimac (Figure 2.15; Table 2.10).

The River Mantaro flows through the Andes mountains at approximately 4000 m AMSL, and 125 km east of Lima. The river is a tributary of the Amazon. A small IBT currently diverts water by gravity from high-level streams in the Mantaro catchment into the headwaters of the Rimac. Water is collected during the three months of high flow, and is stored in a reservoir before it is released into a 10 km-long tunnel through the Continental Divide, for supply during the nine months of low flow. The new proposal would necessitate the enlargement of the current reservoir, so that it could store water that is pumped from the Mantaro, through a vertical lift of 540 m. An initial transfer of 16 m^3 s^{-1} (0.5 x 10^9 m^3 yr^{-1}) is envisaged, which could be increased to a maximum of 35 m^3 s^{-1} (1.1 x 10^9 m^3 yr^{-1}) (Table 2.10). The transfer of water between the two catchments would increase the generation of hydro-electric power in the Rimac River basin. Furthermore, flow in the Mantaro would be regulated through storage in Lake Junin, a natural, shallow lake, which is already used for flow regulation for a downstream power station.

Figure 2.15 The location of the two IBT schemes in Peru and Brazil, described in the text. 1, Paraíba-Lajes Transfer; 2, Lima water supply.

Table 2.10 A list of South American IBTs.

Country	Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred (x 10^6 m^3 yr^{-1})
Brazil		hydro-electric power	I II	Piraí Paraíba	Lajes Piraí and Lajes	5045
Peru	Lima water supply	hydro-electric power and municipal supply		Mantaro	Rimac	1100

2.3. Continental Asia

2.3.1 Russia and Kazakhstan

The Russians have, since the last century, considered a variety of proposals for IBTs, some of which are significant even on a global scale (Micklin, 1969; Voropaev and Velikanov, 1985; Micklin, 1986). Russia has a plentiful supply of freshwater (20% of the global supply) with available resources exceeding consumption by some 15- to 18-fold. However, like most countries that find it necessary to construct IBT schemes, there is a major continental bias in the spatial distribution of these resources, with 84% of freshwater resources present in Siberia, far eastern and northern Russia and only 16% in southern and central Russia, and in Kazakhstan, where 75% of the population and 80% of production occurs. In recent decades, two particular projects have occupied interdisciplinary research teams. These are the European Transfer Project (ETP), which involves the redistribution of water resources of northern rivers and lakes to the Caspian Sea Basin in the south, and the Siberia-Central Asia Project (SCAP), comprising the diversion of Siberian rivers to various regions in the Urals, Western Siberia, central Russia and neighbouring Kazakhstan. If completed, these diversions would have transferred an annual volume of 120 x 10^9 m^3 of water, and although this volume is not the largest ever proposed, the potential impacts of these transfers would have surpassed those of all existing transfer schemes globally. Due to the size and extent of these proposed schemes, an extensive multi-disciplinary research programme was initiated in 1977, which aimed at identifying and analysing potential environmental and ecological effects of these IBTs. Due to the negative effects encountered by this programme, the first of these proposals, SCAP, was shelved in November 1985, while the ETP was abandoned in March 1986 (Micklin, 1986).

Largely as a result of environmental impact studies, the original design of the ETP was altered several times prior to its abandonment. The principal motivations behind the ETP were to compensate for growth in water demand in the Caspian and Azov Seas drainage basins, where over-exploitation of water resources has led to dramatic decreases in water levels of the two inland seas (Voropaev and Kosarev, 1982; Voropaev and Velikanov, 1985). Furthermore, the scheme would lead to the development of irrigation and improvement of general water supply in receiving catchments. Phase I of the ETP proposed a transfer of between 2.2 and 5.8 x 10^9 m^3 yr^{-1} of water from the Upper Sukhona River and lakes Lacha, Vozhe and Kubena to the Rybinsk Reservoir on the Upper Volga. Phase II would have transferred 3.5 x 10^9 m^3 yr^{-1} from Lake Onega *via* the Phase Ia route, while Phase III would have added a further 9.8 x 10^9 m^3 yr^{-1} from the upper reaches of the Pechora, *via* an extensive system of dams, to the Kama River, a tributary of the Volga (Figure 2.16; Table 2.11). The ETP would thus have transferred a total of 19.1 x 10^9 m^3 yr^{-1}, enabling a projected increase in agricultural production and hydro-electric power generation, while maintaining and creating navigation routes. The total cost of the project, at 1982 prices, was estimated at over US$3 billion (Micklin, 1985).

The Siberia-Central Asia Project (SCAP) was primarily designed for irrigation supply in Russia and Kazakhstan (Voropaev and Velikanov, 1985), to take pressure off inland ecosystems such as the Aral Sea, the fourth largest inland sea in the world. The project was to abstract approximately 27 x 10^9 m^3 yr^{-1} of water from the Ob River, below its confluence with the Irtysh, for southward transfer along a 2500 km-long, unlined canal, to the Syrdar'ya and Amudar'ya rivers in Russia (Figure 2.16; Table 2.11). It was proposed that the transfer from the Ob would occur either along a canal, or by the total reversal of flow in the Irtysh, effected by several pumping stations and four dams. During high-flow months (May-August), water was to be taken from the furthest upstream reservoir on the Irtysh, while during low-flow months, water would have been pumped from the Ob, upstream along the Irtysh and into the Tobolsk Reservoir (Dodd, 1986), ready for transfer into the Syrdar'ya catchment. Water was to be used along the length of the transfer route, and the final recipient, the Amudar'ya, would have received 9 x 10^9 m^3 yr^{-1}.

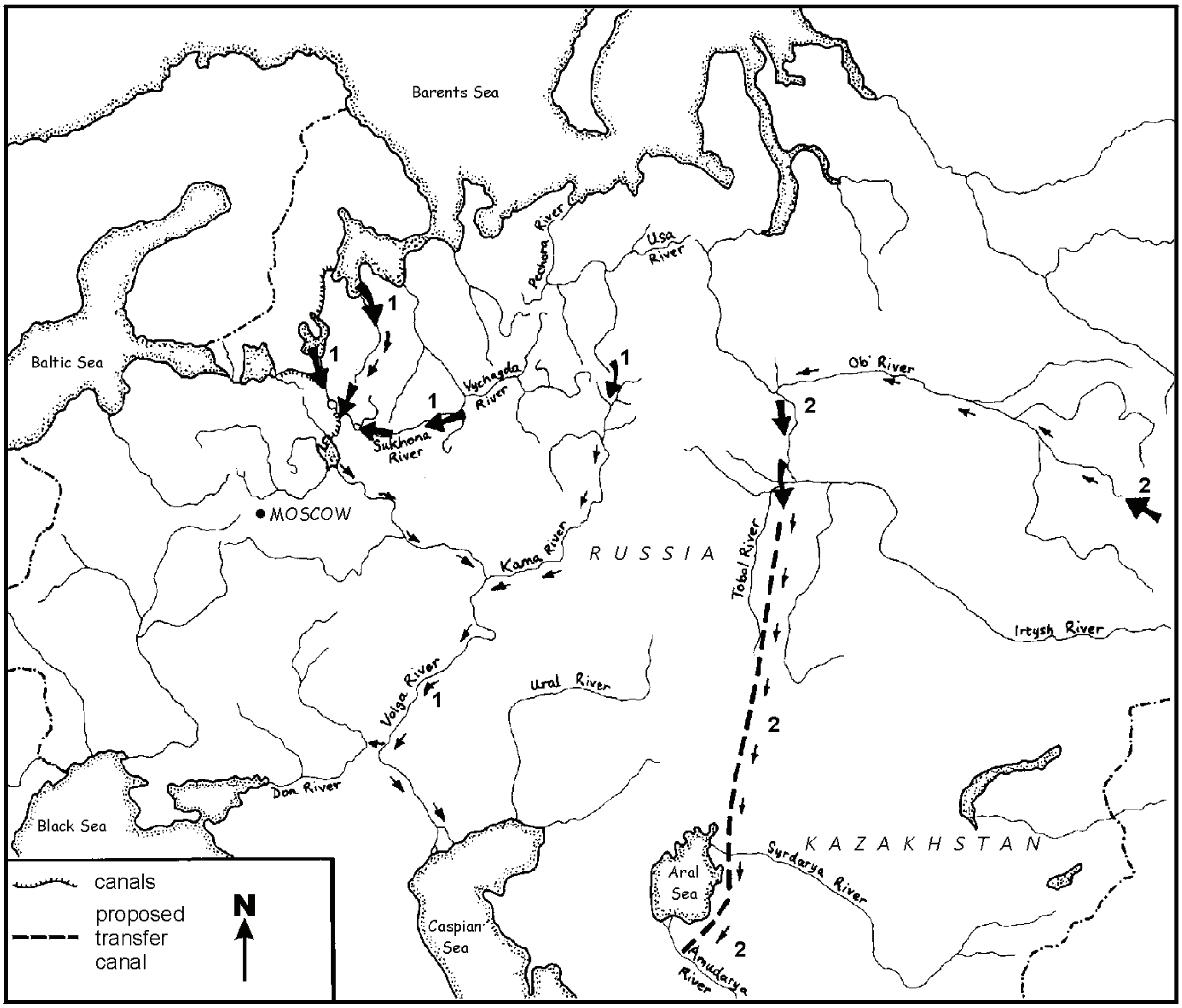


Figure 2.16 A map of the proposed routes for the European Transfer Project (ETP, 1), and the Siberia-Central Asia Project (SCAP, 2), in Russia and Kazakhstan.

However, the project would not have provided water directly to the Aral Sea, and thus would not have alleviated the problem of water supply to the Aral Sea (e.g. Micklin, 1988) nor would it have halted the ecological damage to the Syrdar'ya and Amudar'ya deltas, as much of the flow in these rivers is diverted for irrigation (Pearce, 1995c,d). In order to alleviate the problems of the Aral Sea, a further phase of the SCAP project would be necessary. This would have raised the total transfer to 60 x 10^9 m^3, and in order to compensate for this abstraction, the Ob River would have received an additional transfer from the Yenisey River (Micklin, 1988).

A further scheme that has been proposed, known as the Danube-Dnieper Water Resources Utilisation System, would involve impoundment of the Danube, reservoir construction on the Dniester, Dnieper and South Bug estuaries and salt water lagoons along the Black Sea (lakes Sasyk, Khadzhibey, Tiligul and Berezan), in order to transfer water *via* a series of tunnels and canals to the rich farmlands of the southern Ukraine (Romanenko *et* *al*., 1982) (Table 2.11). There are several schemes in Russia which have been in use for many years. There is a diversion from the Volga River to the Moskva River, which flows through Moscow; the 480 km-long Irtysh-Karaganda Canal, completed in 1971, which is used primarily for industry and irrigation in central Kazakhstan (Nace, 1974); the Severskiy Donets-Donbas Canal; a 403 km-long diversion from the Dnieper to the North Crimean Canal; the Oka-Don-Oskol Water Management System; and a diversion from the Amudar'ya to the Kara Kum Canal, which has a maximum capacity of 300 $m^3 s^{-1}$ (9 x 10^9 $m^3 yr^{-1}$) (Table 2.11). The total transfer volume of these schemes is approximately 40 x 10^6 $m^3 yr^{-1}$ (Antonov, 1976).

Table 2.11 Current and proposed IBT schemes in Central Asia.

Country	Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred (10^6 $m^3 yr^{-1}$)
Russia	-	-	-	Volga	Moskva	
Russia	North Crimean Canal	irrigation	-	Dnieper	Various	
Russia	Severskiy Donets-Donbas Canal					
Russia	Oka-Don-Oskol Water Management System					
Russia	Kara Kum Canal	-	-	Amudar'ya	Various	
Kazakhstan	Irtysh-Karaganda Canal	industry and irrigation		Irtysh	Karaganda	
Proposed:						
Russia	European Transfer Project	irrigation and general supply	I II III	Sukhona Lake Onega Pechora	Volga Volga Kama (Volga)	2200 - 5800 3500 9800
Russia/ Kazakhstan	Siberia-Central Asia Project	irrigation and replenishment of inland seas	I II	Ob Yenisey	Syrdar'ya and Amudar'ya Ob	27 000 60 000
	Danube-Dnieper Water Resources Utilisation System	general supply	-	Danube	Southern Ukraine	

2.3.2 People's Republic of China and the Far East

The location of China in relation to the Indian Ocean in the south, the Pacific Ocean to the east, and the continent of Asia to the north-west, leads to a gradient of rainfall which increases from north to south, and from north-west to south-east of the country (Dakang, 1983). Annual rainfall exceeds 500 mm in the south-east of the country, but is often far less than this - 150 to 250 mm in some provinces - in the north-west. In the catchment of the Yangtze (Chang Jiang) River, rainfall averages a reliable 1100 mm yr^{-1}. The monsoon climate that predominates in this area, leads to a marked seasonality of rainfall, with the heaviest rains falling, almost without exception, in summer. In the more northern latitudes, summer rainfall occurs during storm events, and it accounts for a greater percentage of the total annual rainfall. Thus total precipitation in the north of the country is determined by the number and frequency of rain storms, which vary from year to year. Water resources are thus unpredictable in this region. Most water is needed during spring, which is the growing season for wheat, and the sowing season for autumn-harvested crops. However, spring rainfall is scarce, especially in the north, and also on the North China Plain which is the most productive agricultural area in China, lying to the north of the Huai River. During the spring months, air temperatures rise fairly rapidly during the day, and dry winds lead to increased evaporation rates, which often exceed rainfall. Agricultural development on the North China Plain is severely limited by the climate, and the area has been known to experience drought in nine years out of ten (Dakang, 1983).

Surface runoff varies in the same way as climate throughout China, decreasing from south to north and from south-east to north-west, with marked seasonality in the volume of water flowing in the rivers. In spring and winter, the rivers on the North China Plain respectively receive only 10 and 8% of the total annual runoff, while the lack of storage structures leads to much of the summer runoff flowing to the sea. Variation in runoff between years is more marked in rivers to the north and east of the country, with coefficients of variation ranging from between 0.12 and 0.15 for the Yangtze, to between 0.60 and 0.75 for the Hai River.

The Yangtze River, also known as the 'golden waterway' (Changming and Dakang, 1987), is the largest river in China, with a total annual runoff of $980 \times 10^9 m^3$, which constitutes 38% of the total surface runoff of the country. The smaller Huai and Huang rivers contribute respectively 2 and 1.9% to the total runoff (Dakang, 1983). Adding further to the uneven distribution of water in China, is the fact that most of the cultivated and productive land lies in the north. There is thus enough water in the south, but limited agricultural land, while in the north, the opposite is the case. Runoff volume in the south is, on average, 41 700 m^3 ha^{-1}, which is provided by the Yangtze, while, in the north, the Huai and Huang rivers provide, respectively, 4230 and 4290 m^3 ha^{-1}, which amounts to a tenth of the volume available for irrigation in the south.

The imbalances in land, water and human distribution within China have been perceived as major limitations to economic growth and development. In order to address these imbalances China's Ministry of Water Resources and Electric Power have investigated the feasibility of transferring water from the south to the north, *via* three possible routes, which would primarily allow further agricultural development in the recipient areas, but which ultimately would uplift the economy of the whole region and thus lead to further development, both urban and rural (Dakang, 1983, Stone, 1983; Harland, 1988). The proposed transfers would divert water from the Yangtze River in the south to the Yellow River (Huang He), and other smaller rivers in the north. The schemes are collectively referred to as the South-to-North Water Project (SNWP) (Yiqiu, 1981) (Figure 2.17; Table 2.12).

Three routes have been proposed to facilitate the transfer of water from south to north:

- **The Western Route**. This route comprises three separate transfers: (1) from Tontian River to the Qaidam Basin through the Kunlun Mountains, (2) from Jinsha Jiang, a tributary in the upper reaches of the Yangtze, through the Jishi Mountains to the Huang River, and (3) from the Nu Jiang through various rivers to Dingxi County. All of these transfers will divert water from the upper reaches of the Yangtze River (Figure 2.17; Table 2.12). Each of the transfers included in this scheme cuts through mountains, which considerably increases the construction costs, and thus this scheme is not likely to be considered until the next century (Changming *et al*., 1985; Changming and Dakang, 1987).

- **The Middle Route**. This is a two-phase scheme transferring water initially from the extant Dangjiangkou Reservoir (on the Han Jiang, a tributary of the Yangtze) to the Beijing district, and secondly drawing water from the Three Gorges Dam (almost complete) on the middle reaches of the Yangtze River and transferring it to the Dangjiangkou Reservoir (Figure 2.17; Table 2.12).

- **The East Route**. This third route will use part of the extant Beijing-Hangzhou Grand Canal (see Section 1.1) to transfer water from the lower reaches of the Yangtze at Jiangdu to the North China Plain (Figure 2.17; Table 2.12), and is thus a cheaper and easier alternative. The Grand Canal is, at present, silted up, but the canal will be dredged, pumps installed, and water pumped from the Yangtze to the Yellow River.

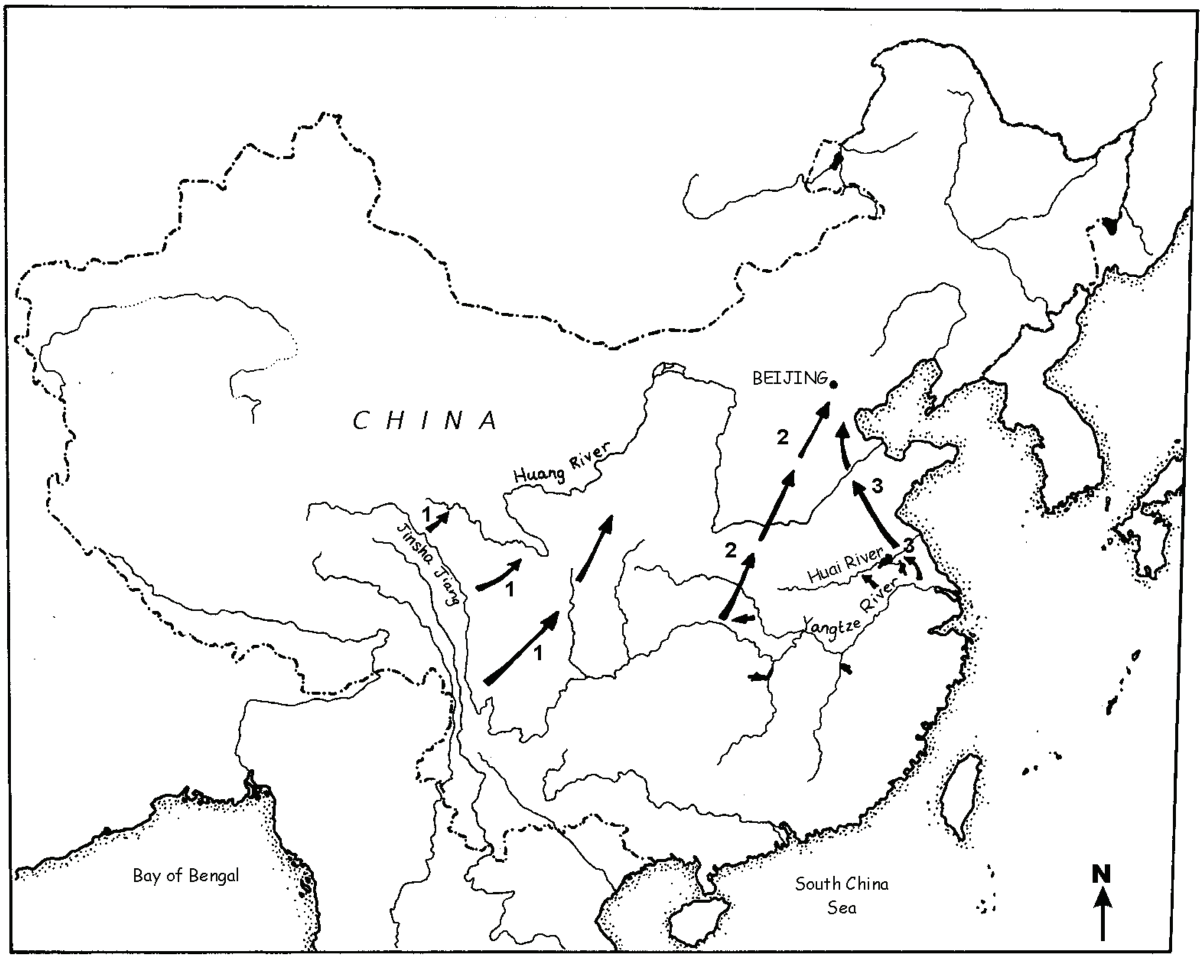


Figure 2.17 The proposed Western (1), Middle (2) and Eastern (3) Routes of the South-to-North transfers in China.

The East Route was approved by the State Council in 1983, and construction has already begun; hence this route has been described in detail by Changming *et al.* (1985). The East Route comprises two stages. In the first stage, water abstracted at the Jiangdu Pump Station on the Yangtze will be transferred *via* Hongze Lake (on the Huai River), Luoma Lake (on the Yi River) and Nansi Lake, to Dongping Lake on the Dawen River, along a 646 km-long canal (Figure 2.17; Table 2.12). This first stage coincides with an existing IBT scheme in the north of Jiangsu Province, on which construction began in the early 1960s. This multipurpose IBT involves the transfer of water from the Yangtze River to the Huai River and then northwards to the Yi-Shu-Si River basin (Figure 2.17; Table 2.12). The second stage of the proposed East Route will continue the transfer, *via* canals and tunnels, under the Yellow River and into Beidagang Reservoir, which is situated near, and supplies water to, Tianjin City. The total combined volume of water that will be transferred is 1000 $m^3\ s^{-1}$, which represents a total transfer of 14 x $10^9\ m^3\ yr^{-1}$, rising to 30 x $10^9\ m^3\ yr^{-1}$ in drought years, with the addition of water from the Yellow River (Table 2.12). The transfer will go under the Yellow River in order to avoid the inevitable massive increase in suspended solids that an overland route would entail. The Yellow is the most turbid river in the world, exporting some 2 billion tonnes of sediment to the sea per year (Harland, 1988). Thus, Yellow River water will only be used when absolutely necessary. The East Route will also harness the run-off of the Huai River basin. The three schemes together would eventually transfer some 1200 $m^3\ s^{-1}$ (39 x $10^9\ m^3\ yr^{-1}$) of water per year to the north.

With regards to the Middle Route, the Three Gorges Dam will form the major storage unit for the transfer. The main purposes of the Three Gorges Dam is to provide flood control in the catchment, hydro-electric power generation, and to improve navigation along the Yangtze River (Kwai-Cheong, 1995). Construction on the Three Gorges Dam began in December 1992, despite pressure from within China and from other countries to reconsider the project (Burton, 1994; Pearce, 1995a). The dam will take approximately 15 years to complete, at a cost of between US$22 and US$34 billion, although, taking interest and inflation into account, some estimates reach the US$70 billion mark. The dam will be approximately 175 m high and nearly 2 km long, damming approximately 500 km of river behind it. The hydro-electric power generating capacity is estimated at 18 000 MW, which is substantially greater than that generated by the world's largest hydro-electric power station at Itaipú Dam in Paraguay (Pearce, 1995a; McCully, 1996).

Japan is an archipelago, and thus provides some interesting examples of water transfer on fairly small scales (Okamoto, 1983). The islands are situated within the Asian monsoon area and are thus subject to typhoons and heavy rain events. Japan has abundant annual precipitation but the monthly distribution is not uniform, affecting agriculture, primarily paddy fields that depend almost exclusively on irrigation. There are few rain-fed rice paddies in Japan, and, currently, almost all of the reliable runoff is diverted to the paddy fields.

The transfer of water in Japan has occurred throughout history. The Tama River Water Supply System was built in the middle of the 17th century to provide for the domestic water demands of Edo (now Tokyo). With population growth, the area of land cultivated for rice in Japan has steadily expanded and, currently, the available runoff is no longer sufficient to meet irrigation demands. Even during years of good rainfall there is little excess runoff as more paddy fields are reclaimed and require irrigation. The growth of cities and towns throughout Japan has placed further stresses on the water resources of the islands.

Due to the topography of the country and the small size of the river catchments - the largest is 17 000 km^2 - impoundments tend to be small, and are designed to supply water from month-to-month, rather than between years (Okamoto, 1983). New water sources are continually sought, and the diversion of water between rivers has become a necessity in order to allow the expansion of cities, towns, industry and agriculture. The technology associated with water transfer has grown and improved in Japan, such as the introduction of pumps, improved tunnel excavation techniques and water diversion methods. Previously unlikely transfer options are now being assessed.

After the Second World War, the Japanese Government provided financial assistance to an electric power company to produce hydro-electric power, as well as providing substantial subsidies to farmers for irrigation water and the construction of irrigation schemes. Presently, the Japanese Government has a policy of partially funding multipurpose water schemes (Okamoto, 1983). There are thus considerable financial incentives in Japan for the construction of large, multi-purpose water schemes.

In terms of water rights and, according to Japanese law, all surface runoff is regarded as public property, and thus water rights must be granted by the government before a river is impounded or diverted. However, due to the long history of agricultural use of water, most agricultural water rights were entrenched long before the institution of the 'public water' law (Okamoto, 1983). The practical outcome of this is that farmers have automatic and undisputed entitlement to water rights, which has led to many disputes, especially in cases where water is diverted from downstream users.

By the early 20th century, the Tama River Water Supply System was supplying a total of $50 \times 10^6\ m^3\ yr^{-1}$ to meet the water needs of the growing city of Tokyo. By the mid-1930s, however, it became necessary to build two storage tanks in Tokyo to store some of the $300 \times 10^6\ m^3\ yr^{-1}$ which was required from the Tama River. In order to supply water to its 7 million inhabitants, the total transfer of water to Tokyo in the 1960s exceeded $1 \times 10^9\ m^3\ yr^{-1}$. An impoundment on the Tama River became a necessity, but to ensure a continued supply of water to Tokyo while this dam was constructed, water was diverted from the Edo River and from the Sagami River to the Tama River (Figure 2.18; Table 2.12). This supply soon proved inadequate, and the city looked further afield to the Tone River, which is the largest river in Japan. Subsequently, tributaries of the Tone River were impounded to augment water supply to the city, and a further IBT from the Sakawa to the Sagami River and on to Tokyo is now extant. Tokyo City is currently considering diverting water from rivers even further away, such as the Naka, Agamo, Shinano, and Fuji rivers (Figure 2.18).

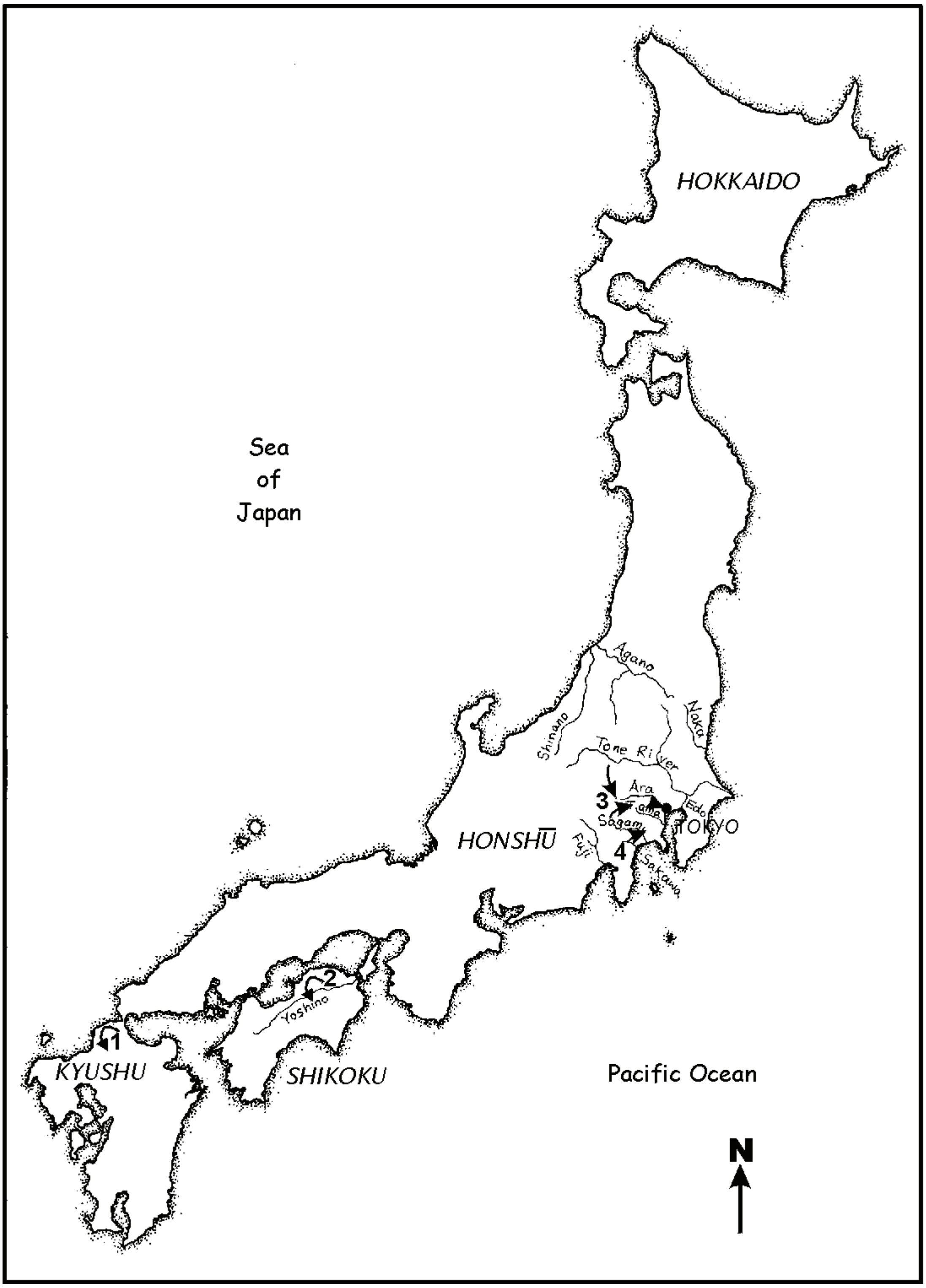


Figure 2.18 A map showing the location of the IBT schemes in Japan which are reviewed in the text. 1, Shin-Nippon Seitetsu Kabushiki Kaisha Scheme; 2, Kagawa Irrigation Project; 3, Tama River water supply system; 4, Sakawa-Sagami Transfer.

This proliferation of diversion schemes within Japan has been met by concerns about the environmental and social consequences of these large water projects. Many local people are beginning to doubt the necessity of an unlimited search for further water supplies, when reductions in water consumption and more efficient use of the resource could prolong the adequacy of current supply (Okamoto, 1983).

Apart from water supply to Tokyo, other IBT schemes exist, including the Kagawa Irrigation Project and Shin-Nippon Seitetsu Kabushiki Kaisha Scheme. The Kagawa Irrigation Project is located on the island of Shikoku, the northern region of which is the driest district in Japan. After the Second World War, political opposition to the Irrigation Project was resolved, and the main storage reservoir for the scheme was built on the Yoshino River, which flows in the east of the island (Figure 2.18; Table 2.12). Water is transferred to the area of demand through a tunnel which was excavated through a mountain range.

The Shin-Nippon Seitetsu Kabushiki Kaisha Scheme was constructed in order to supply water to one of the largest iron-manufacturing plants in the world. Local water supply proved inadequate for the plant, and water is now diverted from the Onga River and stored at the plant in large storage reservoirs, with volumes ranging from 1.5 to 7 x 10^6 m^3 (Figure 2.18; Table 2.12). Once this supply fell short of demand, a storage reservoir was built on the Onga River, to ensure continued year-round supply.

The only effects of IBTs in Japan that have been investigated are those associated with the socio-economic impacts related to loss of land, and the consequences of reduced irrigation supplies in the donor basins (Okamoto, 1983). There appears to be very little literature on the ecological, geomorphological and social effects of IBTs in Japan.

Table 2.12 A list of IBT schemes in China and Japan.

Country	Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred (10^6 m^3 yr^{-1})
China	-	multi-purpose	-	Yangtze	Yi-Shu-Si	
Japan	Shin-Nippon Seitetsu Kabushiki Kaisha Scheme	industry	-	Onga River	Iron-manufacturing plant	1.5-7
Japan	Kagawa Irrigation Project	irrigation	-	Yoshino River	Irrigated lands	
Japan	Tama River water supply system	municipal supply	I	Tama River	Tokyo City	1000
			II	Edo River, Sagami River	Tama River	-
			III	Tone River	Tama River	-
Japan	-	municipal supply	I	Sakawa River	Sagami River	-
Proposed:						
China	South to North Water Project: *Western Route*	general supply	I	Tontian (Yangtze)	Qaidam	-
			II	Jinsha Jiang (Yangtze)	Huang	-
			III	Nu Jiang (Yangtze)	Dingxi County	-
	Middle Route		I	Han Jiang (Yangtze)	Beijing District	-
			II	Yangtze	Han Jiang	-
	East Route		I	Yangtze	Dawen	-
			II	Yangtze, Yellow, Huai	Tianjin City/North China Plain	14 000 - 30 000

2.3.3 *The Indian sub-continent and Sri Lanka*

Long distance water transfer has been practised in India for over five centuries (Gole and Murthy, 1978; Murthy, 1978). Rainfall is highly seasonal, with most falling during the monsoon season, from July through to September, although there may be dry periods between monsoons. Furthermore, the distribution of this rainfall is fairly uneven, causing flooding in some parts and deficits in others. The eastern parts of the Himalayas and the mountain ranges along the west coast of India receive a MAP of 4000 mm yr^{-1}, while the eastern parts of the country receive a phenomenal 10 000 mm yr^{-1}. Agriculture is the predominant activity and, thus, all existing IBTs in India provide irrigation water and as such, are consumptive; no water is released to a recipient river (Gole and Murthy, 1978). Most IBT schemes in India divert water from westward-flowing rivers to the dry eastern plateau. In the middle of the 19th century canals were constructed from the Ganga, Godavari and Krishna rivers, across several streams and valleys, to the east of the country in order to extend irrigated agriculture. Several new schemes are now under investigation, however, particularly the Godavari-Krishna-Pennar IBT, which will eventually transfer water from the water-rich Godavari River Basin to the water-deficient Krishna and Penner basins (the last basin in Andhra Pradesh would also supply the city of Madras) (Figure 2.19; Table 2.13). The Bodhghat Dam Project on the Indravati River (which was designed to produce 107 MW of hydro-electric power), forms part of a series of dams for the development of the Indravati and Godavari rivers. The link from the Krishna to the Pennar has already been approved and the other connection from the Godavari is still awaiting approval by the Godavari Tribunal. It is the inter-state aspect of this scheme that has delayed implementation of the transfer.

Other schemes include the Brahmaputra-Ganga Link, an international scheme involving Bangladesh, that will enable flood control, hydro-electric power production and irrigation development in the lower Ganga-Brahmaputra region (Figure 2.19; Table 2.13). A further IBT proposal, the Narmada High Level Canal has been the subject of a protracted and bitter battle since its conception by the Gujarat Government. The scheme envisages the construction of a high dam at Navagaun which will transfer water across several rivers and streams to the areas of North Gujarat and Kutch enabling the development and irrigation of 5.7 million acres. It is also the subject of an inter-state dispute.

A French engineering company, Electricité de France, aided in the design of the Mahaweli-Ganga Project, in Sri Lanka (Morel, 1978). This IBT transfers 25 $m^3 s^{-1}$ (0.8 x 10^9 $m^3 yr^{-1}$) of water primarily for irrigation purposes through two successive tunnels (total length 12.5 km) from rivers on the eastern end of the island (Mahaweli Basin) to the drier western slopes (Ganga Basin) (Figure 2.19; Table 2.13).

Table 2.13 A list of extant and proposed IBT schemes in and around India and Sri Lanka.

Country	Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred (x 10^6 $m^3 yr^{-1}$)
India	Godavari-Krishna-Pennar Link	irrigation	I	Godavari	Krishna	-
			II	Krishna	Pennar	-
Sri Lanka	Mahaweli-Ganga Project	irrigation	-	Mahaweli	Ganga	-
Proposed:						
India	Narmada High Level Canal	-	-	Narmada	Gujarat Region	34 690
India	Brahmaputra-Ganga Link	flood control and general supply	-	Brahmaputra	Ganga	-

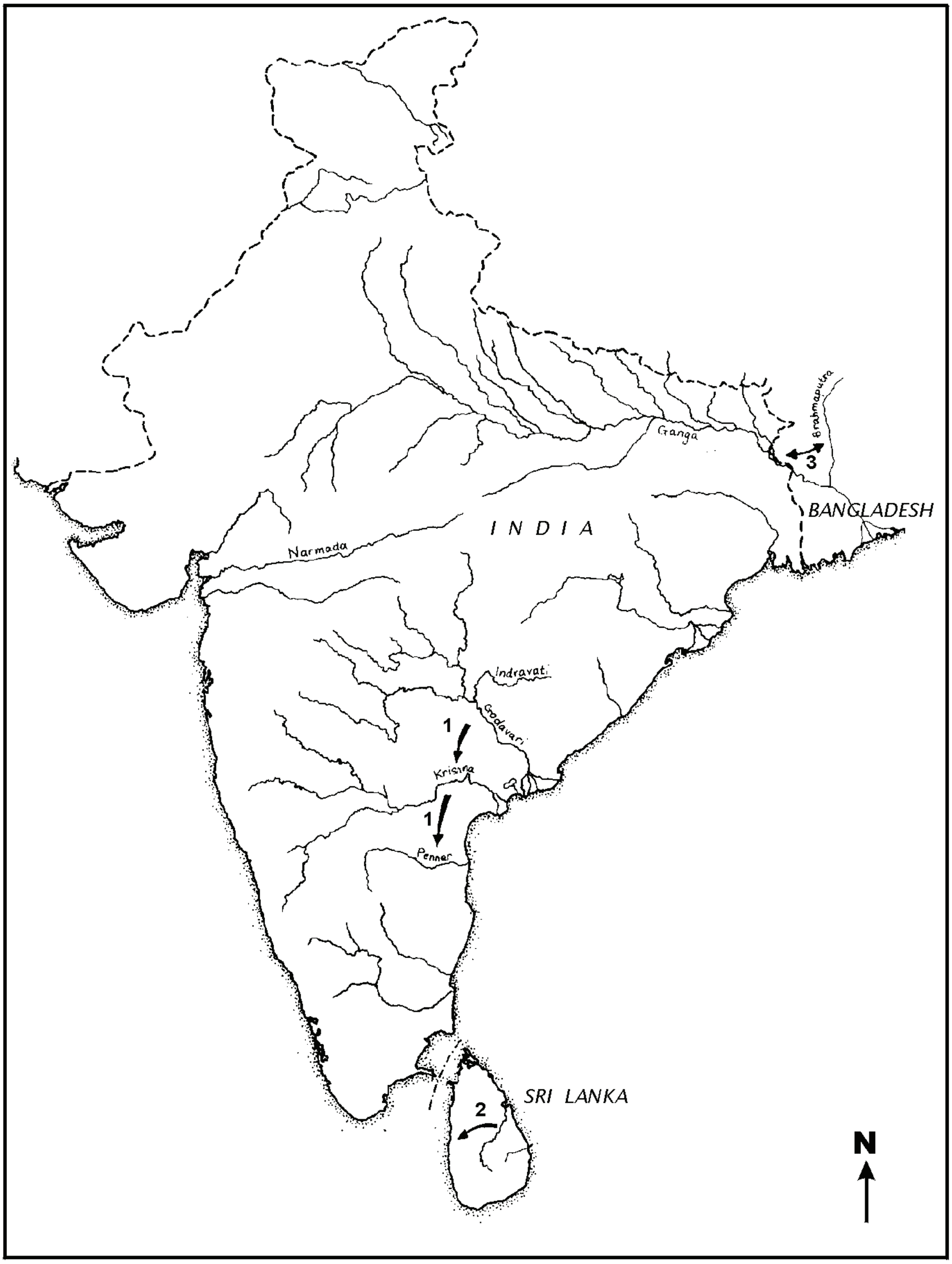


Figure 2.19 The IBT schemes in and around India and Sri Lanka. 1, Godavari-Krishna-Pennar Link; 2, Mahaweli-Ganga Project; 3, Brahmaputra-Ganga Link.

2.4. Australasia

2.4.1 Australia and Tasmania

Australia is a dry continent, because of its relatively small land area (8.42 x 10^6 km^2) and its location between latitudes 15°-35°S. As such it is dominated by sub-tropical high-pressure cells with a low moisture content. Furthermore, only 7% of the land area lies above 600 mAMSL, leading to a MAP of 420 mm for the continent, of which only *ca* 50 mm yr^{-1} is converted into runoff. These figures are low, compared with world averages of 660 mm for precipitation and 250 mm for runoff. However, Australia is a land of hydrological extremes. For example, ratios of maximum to minimum streamflow (an index of flow variability) range from 6 to more than 11 000, which is extremely high in comparison to Europe (3-10) and North America (3-15).

Spatial variations also are notable: annual runoff for various regions ranges from more than 3500 mm in coastal areas, to less than 12.5 mm for more than 75% of the continent. The greatest proportion of the total runoff occurs in the northern and north-eastern coastal areas, with 88% of the total annual runoff coming from only 26% of the land area. Thus, the location of water resources and their availability relative to agricultural and industrial resources and population concentrations is of great concern (Pigram, 1986).

Given this variable supply and distribution, IBTs become attractive development options. There are 24 major lBTs supplying water for urban and irrigation purposes, as well as for hydro-electric power generation. The majority involve diversion of coastal rivers along the eastern seaboard, inland to the Murray-Darling Basin, and with increased agricultural production in the basin, further developments can be expected (Pigram, 1986). Studies by the New South Wales Water Resources Commission, have revealed 40 possible schemes for future IBTs to inland basins in that state alone (Rankine and Hill Pty Limited, 1981).

Only four studies have investigated IBTs in Australia, despite the reliance on these schemes for adequate water supply in parts of the country. It is noteworthy that these studies were undertaken well after the completion of the projects. There have been no environmental impact studies on IBTs in Australia. Of the studies that have been completed only one has been comprehensive, including hydrological, geomorphological, ecological and economic analyses. However, the results of some of these studies have not been released to the public by the various government agencies. These four IBT schemes are described below.

The largest IBT in Australia, the Snowy Mountains Scheme, involves the transfer of 1.1 x 10^9 m^3 yr^{-1} of water from the coastal Snowy River into the upper Murray and Murrumbidgee rivers, which flow westwards (Figure 2.20; Table 2.14). Johnson and Millner (1978) have reviewed the technical and general impacts of the system. The scheme evolved from the Commonwealth Government's right to develop the water resources of the Snowy River for hydro-electric power generation for Canberra, the Federal capital. This right was exercised in 1949 with the support of the Victorian and New South Wales State Governments. The scheme, built between 1949 and 1974, embraces an area of 7000 km^2 and involves 15 major dams, many smaller diversion structures, 150 km of tunnels, seven power stations, a pumping station, and 80 km of aqueducts, all at a cost of US $900 million.

The scheme has two broad sections: the Snowy-Tumut development and Snowy-Murray development. The Snowy-Tumut development consists of diversions from the Upper Murrumbidgee (from Lake Tantangara), Lake Eucumbene (on the Eucumbene, a tributary of the Snowy River), and the Tooma River (a tributary of the Upper Murray), to the Upper Tumut (a tributary of the Murrumbidgee) over the Great Dividing Range (Figure 2.20; Table 2.14). Additional flow is provided by diverting the Cooma River (which flows in to the Murray) to the Tumut River: this diverted flow provides 2.18 x 10^6 KW hydro-electric power generation from four power stations before it is released into the Murrumbidgee. The Snowy-Murray development consists of the diversion from Lake Jindabyne on the Snowy River *via* a couple of its smaller tributaries, through tunnels to the Murray River (Figure 2.20; Table 2.14). Further details are provided by Johnson and Millner (1978) and Davies *et al*. (1992).

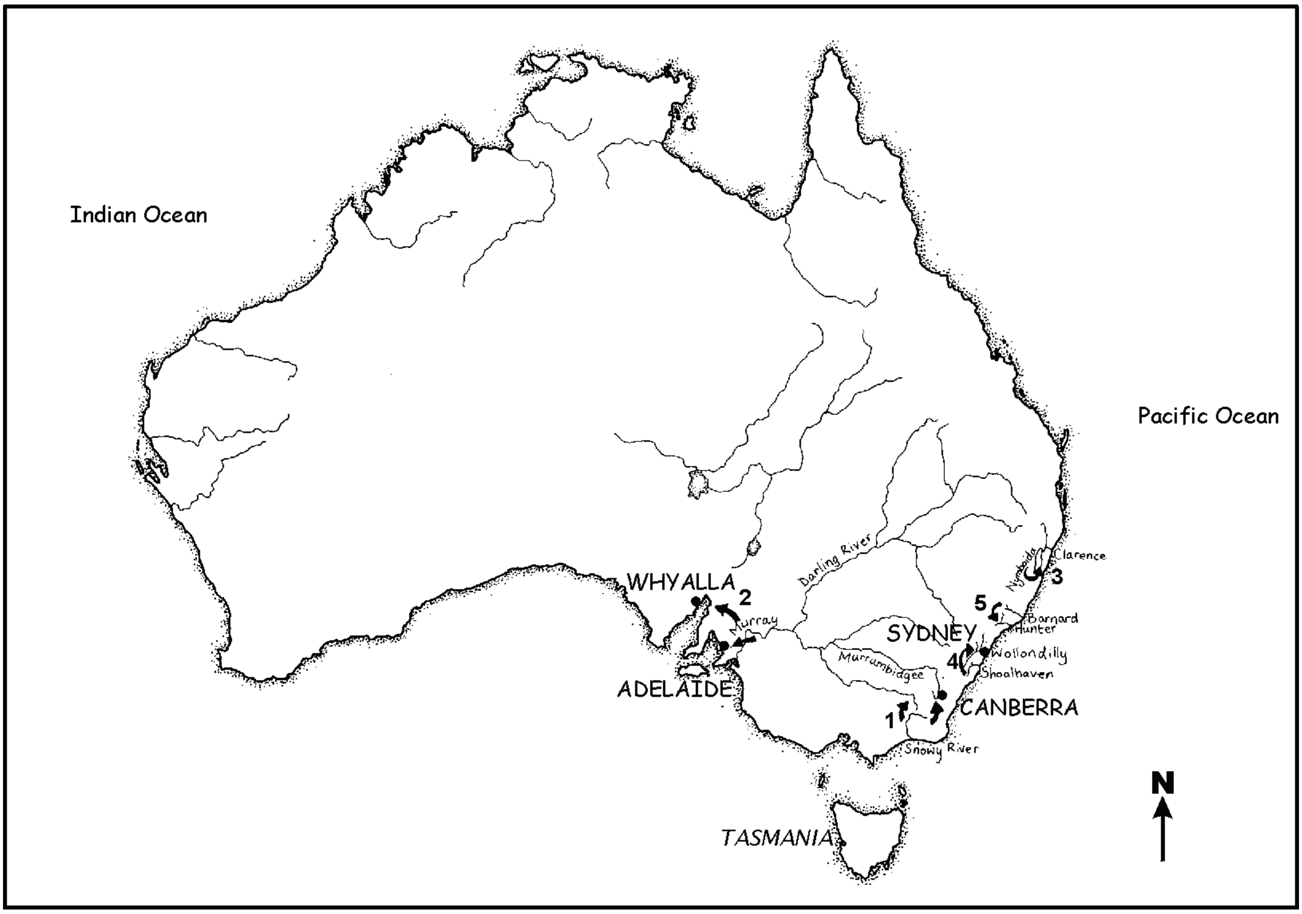


Figure 2.20 A map showing the location of five IBT schemes in Australia. 1, Snowy Mountains Scheme; 2, Lower River Murray transfers; 3, Nymboida-Blaxlands Scheme; 4, Shoalhaven-Wingecarribee; 5, Barnard-Hunter Scheme.

The Lower River Murray transfers comprise diversions from the lower reaches of the River Murray in South Australia, to the headwaters of eight small catchments in the Adelaide/Whyalla region (Figure 2.20; Table 2.14). The infrastructure is complex, involving 15 dams, 48 pumping stations, 120 holding tanks and over 1000 km of pipeline. On average, 40% of Adelaide's annual water supply comes *via* the Swan Reach, Mannum and Murray Bridge pipeline systems, constructed between 1940 and 1973. During low rainfall years and in summer, these transfers can contribute up to 83% of Adelaide's total water supply of 190 x 10^6 m^3 yr^{-1}.

Located in northern New South Wales, the Nymboida River-Blaxlands Creek Scheme is one of the oldest water transfer schemes in Australia. Although it commenced operation in 1924 it was only granted a licence in 1934 to discharge water under the New South Wales Water Act. Moreover, the licence was only granted in order for landholders to be compensated for loss of land and river front damage downstream of the transfer point in the recipient stream. The diversion was implemented solely for the generation of hydro-electric power and it diverts water from the Nymboida River, a major tributary of the Clarence River, to Goolang Creek and eventually into Blaxland Creek, which eventually joins the Clarence (Figure 2.20; Table 2.14). The initial licence to divert water did not specify a quantity of water, merely enough water to ensure the adequate supply of electricity to the Northern Rivers electricity grid. Current conditions have improved little with no river gauging station on Blaxlands Creek to assess the hydrology of the recipient system. However, field estimates suggest that mean annual discharges have increased by 50%.

The Shoalhaven-Wingecarribee diversion involves the transfer of water from the Shoalhaven River to Wingecarribee Dam for supply to Sydney (Figure 2.20; Table 2.14). From the dam, water can be diverted either to Nepean Dam *via* the Glenquarry Cut, or to Warragamba Dam (Lake Burragorang) *via* the Wingecarribee and Wollondilly rivers. The purpose of the scheme is to transfer excess streamflows during droughts from the Shoalhaven River basin into one of Sydney's water supply dams in the Hawkesbury-Nepean basin. Water is pumped from the Shoalhaven at a maximum rate of 1.5 x 10^6 m^3 day^{-1} (0.5 x 10^9 m^3 yr^{-1}); the active storage capacity of the Wingecarribee Reservoir is 33 x 10^6 m^3. The maximum release rate from the transfer into the Wingecarribee River is 2.7 x 10^6 m^3 day^{-1} (1 x 10^9 m^3 yr^{-1}) (Table 2.14). During droughts, water can be transferred from the Shoalhaven River to Lake Burragorang to supplement Sydney's water supply *via* the Wingecarribee Reservoir and the Wingecarribee River. Although this transfer has been used on occasions, relatively small volumes of water have been involved, and its use has been rare.

A further IBT scheme in New South Wales, involves the annual diversion of up to 20 x 10^6 m^3, from the Barnard River into the Hunter River. This water is used for hydro-electric power generation at two power stations in the Hunter Valley.

Table 2.14 A list of IBT schemes in Australia, as described in the text.

Scheme	Purpose	Phase	Donor	Recipient	Annual Volume Transferred (10^6 m^3 yr^{-1})
Snowy Mountains Scheme	hydro-electric power	I	Murrumbidgee River	Eucumbene River	1130
		II	Eucumbene	Tumut River	-
		III	Cooma River (tributary of the Murray River)	Tumut	-
		IV	Snowy River and tributaries	Murray	-
Lower River Murray transfers	municipal supply	-	Murray	8 catchments in the Adelaide/Whyalla region	157
Nymboida River-Blaxlands Creek Scheme	hydro-electric power	-	Nymboida River (tributary of the Clarence River)	Goolang and Blaxland creeks	-
Shoalhaven-Wingecarribee	municipal supply	-	Shoalhaven River	Wingecarribee River	1000
Barnard-Hunter	hydro-electric power	-	Barnard River	Hunter River	20

2.4.2 New Zealand

The North and South Islands of New Zealand are fairly well-endowed with surface freshwater, but the steep and varied topography of the islands accounts for a dramatic variation in water availability. On South Island, for example, rainfall on the western slopes of the Southern Alps reaches an annual maximum of 5000 mm, while only 330 mm falls on the eastern slopes (Maizels, 1985). Although most of New Zealand's IBT schemes were constructed to augment the hydro-electric power generation capacity of the islands' rivers, in some cases, transferred water has been allocated for irrigation purposes (A.I. McKerchar, New Zealand Department of Scientific and Industrial Research, *in litt*., 22 February, 1991).

An example of this is the Waitaki Power Scheme in MacKenzie Country, South Island. This area is barren and arid, situated in the rain shadow between the Southern Alps and Mount Cook (Maizels, 1985). The Waitaki Power Scheme could more accurately be described as an inter-lake transfer within the Waitaki River basin, and comprises a chain of four power stations, which are linked by 54 km of canals (Figure 2.21; Table 2.15). The Waitaki is fed by three subcatchments in the Southern Alps, which drain into three alpine lakes, Tekapo, Pukaki and Ohau. These lakes are the storage reservoirs for the power stations of the scheme, and are connected by canals to lakes lower down the Waitaki catchment. The rivers which naturally link these lakes have been diverted into the canals. The scheme supplies all the energy requirements of the South Island, and 33% of the requirements of the North Island. A proportion of the diverted water, amounting to 18 m^3 s^{-1} (0.6 x 10^9 m^3 yr^{-1}), has been allocated for irrigation in the MacKenzie area. Similarly, the Rangitata Diversion Race on Central

South Island has a dual purpose, providing water for hydro-electric power generation during winter months and irrigation water during the summer (Maizels, 1985). This scheme diverts water from Rangitata and Ashburton rivers, and releases it into the Rakaia River in winter, and into the Hinds and Ashburton rivers, and coastal, spring-fed creeks (Figure 2.21; Table 2.15).

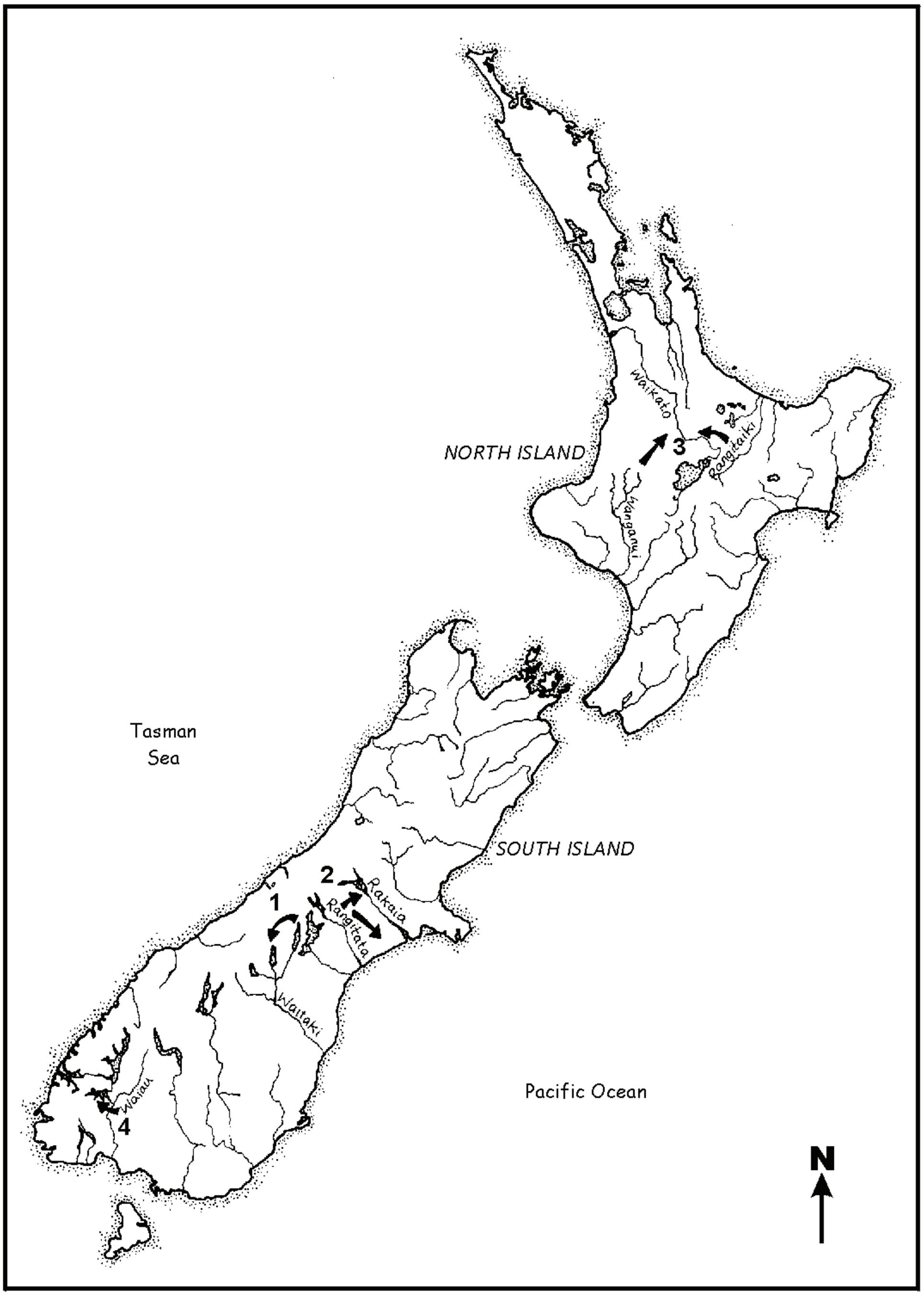


Figure 2.21 The location of four of the IBT schemes mentioned in the text, on the North and South Islands of New Zealand. 1, Waitaki Power Scheme; 2, Rangitata Diversion Race; 3, Tongariro Power Scheme; 4, Manapouri Power Scheme.

IBTs dedicated to the generation of hydro-electric power include the Tongariro Power Scheme on North Island, which links the Wanganui, Rangitaiki and Whangaehu rivers and their tributaries with the Waikato River (Figure 2.21; Table 2.15). The Managahao Power Scheme, North Island, transfers 160 x 10^6 m^3 yr^{-1} from the Mangahao River, a tributary of the Manawatu River, *via* a power plant, into the Tokomaru River in the same basin (Figure 2.21; Table 2.15). On South Island, the Manapouri Power Scheme, not a true IBT, diverts water from the Waiau River, through a power generating unit, which discharges the return flows into the sea, in the Doubtfull Sound (Maizels, 1985).

Table 2.15 IBT schemes in New Zealand (information kindly supplied by A.I. McKerchar, New Zealand Department of Scientific and Industrial Research, *in litt*., 22 February, 1991).

Scheme	Purpose	Donor	Recipient	Annual Volume Transferred (10^6 m^3 yr^{-1})
Waitaki Power Scheme, MacKenzie Country, Central South Island	hydro-electric power, irrigation, flood control	Tekapo (Lake) (Waitaki Basin)	Pukaki (Lake) (Waitaki Basin)	2 340
Rangitata Diversion Race, Mid-Canterbury, Central South Island	hydro-electric power(winter); irrigation (summer)	Rangitata River, Ashbuton River	Winter: Rakaia River; Irrigation season: Hinds and Ashburton rivers, and coastal, spring-fed creeks	730
Tongariro Power Scheme, Central North Island	hydro-electric power	Wanganui, Rangitaiki and Whangaehu Rivers tributaries	Waikato River	1 000
Mangahao Power Scheme, Southern North Island	hydro-electric power	Mangahao River (Manawatu Basin)	Tokomaru River (Manawatu Basin)	160
Manapouri Power Scheme, South West South Island	hydro-electric power	Waiau River	None: power station tailrace drains to sea in the Doubtfull Sound	10 000

2.5. Europe

2.5.1 Scandinavian countries

Norway is the largest *per capita* user of hydro-electric power in the world, and the development and operation of IBTs are almost exclusively for hydro-electric power generation. Many of the rivers of Norway are regulated, giving rise to major environmental effects on inland water courses (e.g. Lillehammer and Saltveit, 1979). Norwegian scientists have undertaken fairly intensive and focused research into the ecological effects of IBTs.

In terms of discharge, the 600 km-long River Glåma is the largest river in Norway (Brittain *et al*., 1984). The river is used for hydro-electric power generation at several sites along its length and, in addition, is the donor system for a water transfer scheme which diverts water from the Høyegga Dam to a hydro-electric power station in the neighbouring Rena River catchment, through a 28 km-long tunnel (Figure 2.22; Table 2.16). Another water transfer in southern Norway diverts water from the glacier-fed, and turbid, Veo River to the largely unregulated Smådøla River, thus feeding a reservoir, Lake Tesse, which is used for hydro-electric power generation (Figure 2.22; Table 2.16). The donor system can contribute up to 68.5% to the annual discharge of the recipient Smådøla River (Hesthagen and Fjellheim, 1987). An additional project in southern Norway, the Aurland Hydropower Scheme, is an intra-basin transfer scheme, involving a complex set of tunnels and pipelines which divert and pump water within the catchment in order to provide optimal power generation from its reservoirs (Faugli, 1994) (Figure 2.22; Table 2.16).

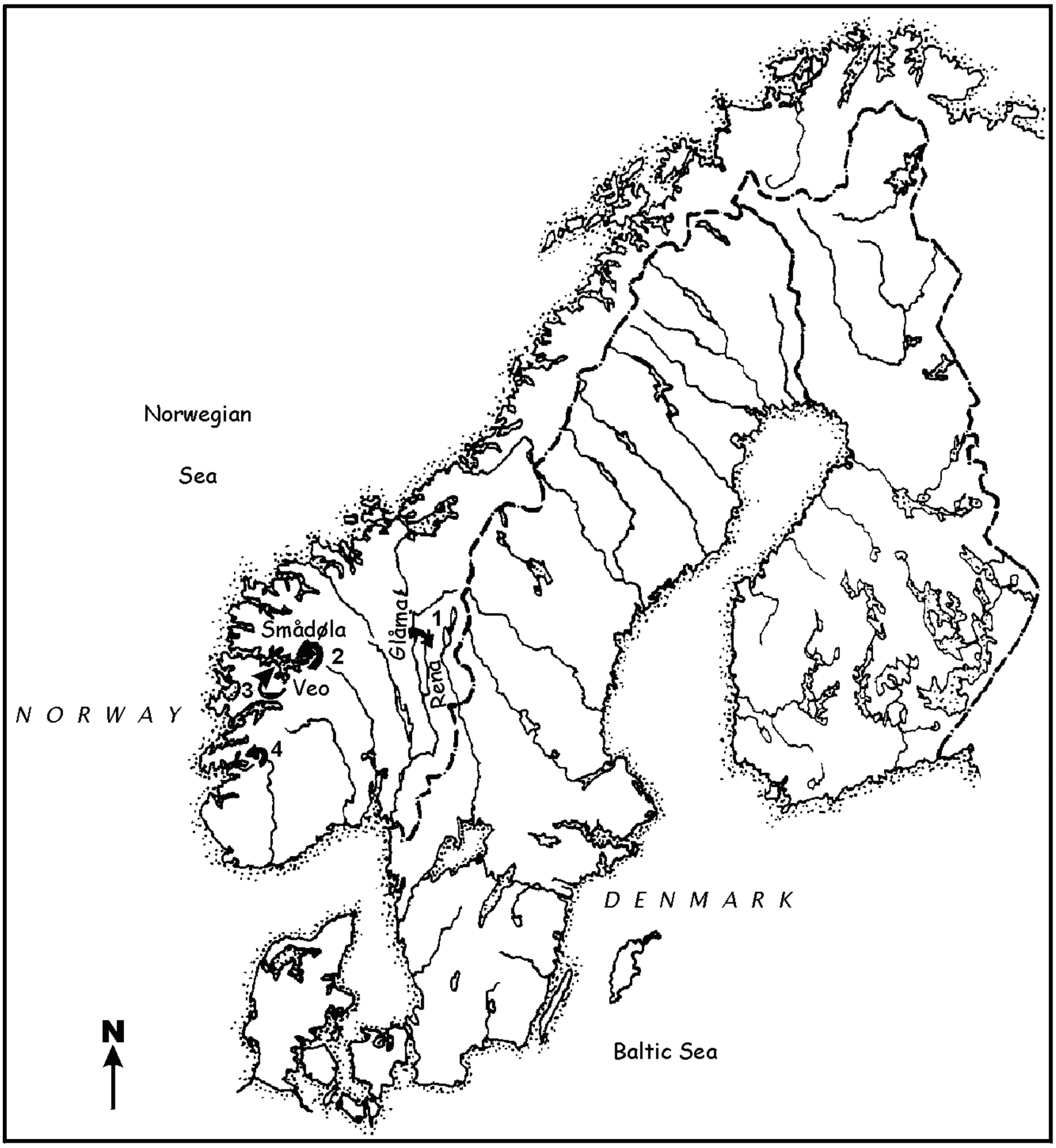


Figure 2.22 A map of Scandinavia, showing the location of IBT schemes described in the text. 1, Glåma-Rena Transfer; 2, Veo-Smådøla Transfer; 3, Aurland Hydropower Scheme; 4, Ulla-Førre hydro-electric power scheme.

Further south, Lake Suldalsvatnet on the headwaters of the 22 km long Suldalslågen River, a well-known Norwegian Atlantic salmon river, supplies water *via* a 2 km-long tunnel to the Ulla-Førre hydro-electric power generating unit on the neighbouring Hylsfjorden (Tøndevold, 1984) (Figure 2.22; Table 2.16).

Table 2.16 A list of Scandinavian IBT schemes, all in Norway.

Scheme	Purpose	Donor	Recipient	Average Transfer Rate (m^3 s^{-1})	Annual Volume Transferred (x 10^6 m^3 yr^{-1})
-	hydro-electric power	Glåma	Rena	-	
-	hydro-electric power	Veo	Smådøla	-	
Aurland Hydropower Scheme	hydro-electric power	Aurland	Aurland	-	
Ulla-Førre hydro-electric power scheme	hydro-electric power	Suldalslågen	Hylsfjorden	6 (winter), 20 (summer)	410

2.5.2 The United Kingdom

The United Kingdom (U.K.) is fortunate in having a plentiful supply of freshwater. However, as a result of a marked east-west gradient in rainfall, and an uneven population distribution, most towns and cities rely on IBTs. These are defined by Petts (1988) as water schemes involving the transfer of water over more than 100 km. This definition is not, however, consistent with the definition used in this review and there are few true IBTs in the U.K., some of which are described here.

The Kielder Water Scheme comprises a transfer of water from the River Tyne to the rivers Wear and Tees (Johnson, 1988) (Figure 2.23; Table 2.17). The Kielder Water Reservoir on the North Tyne River, which acts as the main storage unit for the scheme, stores 188 x 10^6 m^3, and provides hydro-electric power and compensation water releases to the River Tyne. A maximum pumping rate of 6.3 m^3 s^{-1} (0.2 x 10^9 m^3 yr^{-1}) is provided by six pumps at Riding Mill for transfer from the Tyne to the Wear and Tees rivers.

A proposal to transfer water from the River Severn to the Thames River has not been implemented due to the fact that projected water demand has not matched predictions (Brewin and Martin, 1988). However, the Severn-Thames transfer proposal has recently been re-assessed as one of several options for water supply to England and Wales through to the year 2021 (National Rivers Authority, 1994). The Severn-Thames proposal comprises a transfer of a maximum of 4.5 m^3 s^{-1} (0.1 x 10^9 m^3 yr^{-1}) from the Severn to the Thames (Figure 2.23; Table 2.17). The scheme is proposed to make use of a range of transfer route options, one of which is the derelict Thames and Severn Canal. An alternative option proposes a direct transfer of Severn water to users in London. Other transfer options from the Severn include a 2.3 m^3 s^{-1} (0.1 x 10^9 m^3 yr^{-1}) transfer from the Severn to the Trent River, and a 4.5 m^3 s^{-1} (0.14 x 10^9 m^3 yr^{-1}) transfer from the River Wye, to the Severn, for further transfer to the Thames.

The Ely Ouse to Essex Scheme is the only scheme to have received any degree of investigation of the actual effects of transfers. This transfer, devised in order to increase potable water supplies to the Essex area, is able to transfer approximately 0.5 x 10^6 m^3 day^{-1} (0.18 x 10^9 m^3 yr^{-1}) from the Ely Ouse River system to the River Stour at Kirtling Green (Guiver, 1976) (Figure 2.23; Table 2.17). An additional transfer is possible from an off-channel balancing reservoir situated 6 km south of the River Stour, to the rivers Colne or Blackwater. The Ely Ouse water is screened and chlorinated (with subsequent dechlorination) before flowing into the Stour (Boon, 1988).

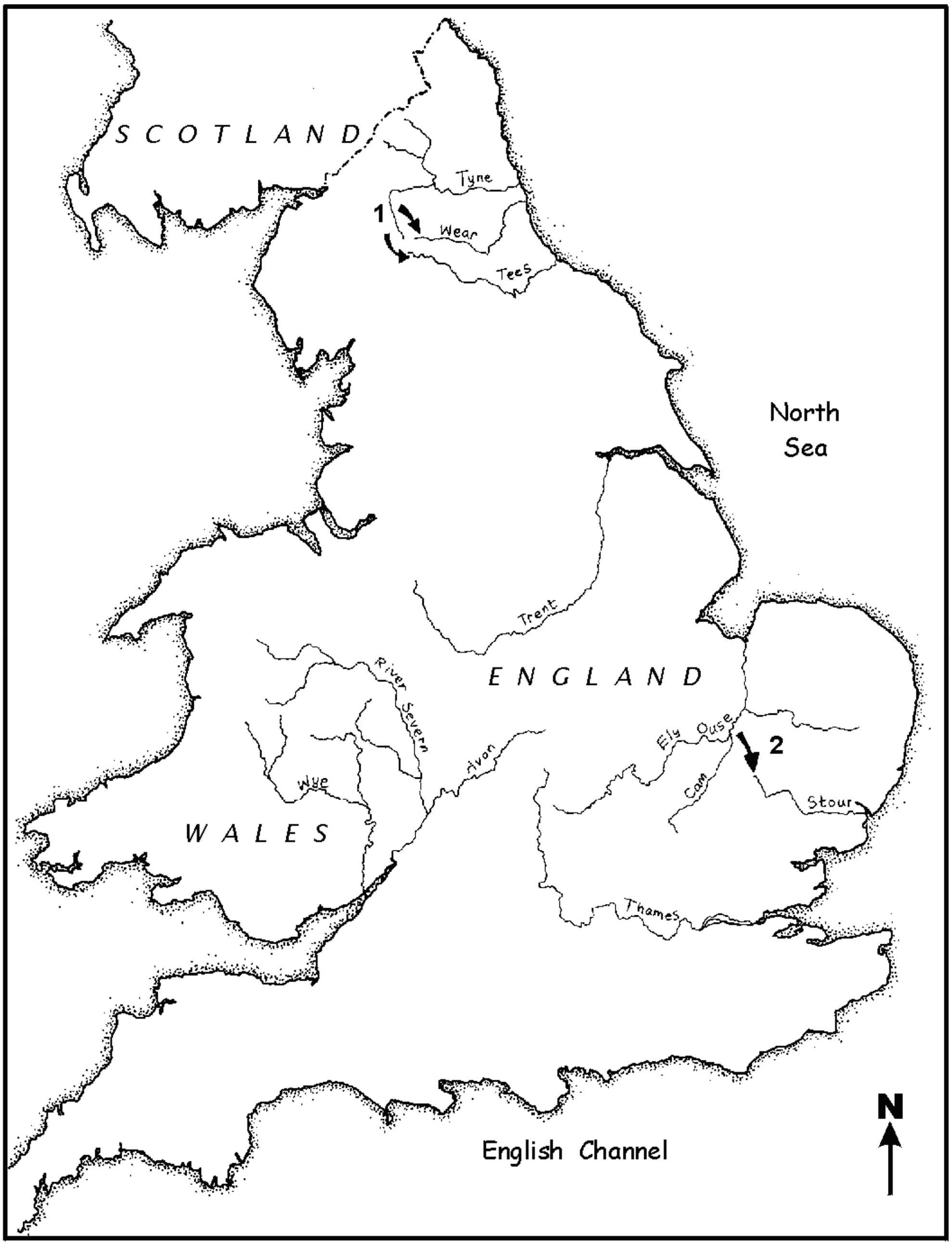


Figure 2.23 Two major existing IBT schemes in the United Kingdom. 1, Kielder Water Scheme; 2, Ely Ouse to Essex Scheme.

Table 2.17 U.K. IBT schemes, all of which are in England and Wales.

Scheme	Purpose	Phase	Donor	Recipient	Average Transfer Rate ($m^3 s^{-1}$)	Annual Volume Transferred ($x 10^6 m^3 yr^{-1}$)
Kielder Water Scheme	hydro-electric power, compensation releases	-	River Tyne	Wear and Tees rivers	6.3	200
Ely Ouse to Essex Scheme		-	Ely Ouse	Stour, Colne and Blackwater	6	180
Proposed:						
Severn-Thames Transfer	General supply	-	Severn	Thames	4.5	140
Severn-Trent Transfer	General supply	-	Severn	Trent	2.3	100
Wye-Thames Transfer	General supply	I II	Wye Severn	Severn Thames	4.5	140

2.5.3 Northern and Central Europe (including former "Eastern Block" countries)

In Slovakia, the River Danube has been diverted into a 35 km navigable canal which flows alongside the natural channel, and which supplies a hydro-electric power station on the right bank of the river (Pearce, 1994) (Figure 2.24; Table 2.18). The Danube is the largest river in Central Europe, originating in the Black Forest in Germany, and flowing east through the Austrian Alps, Slovakia , Hungary, former Yugoslavia and Romania. The river finally flows into the Black Sea. As the river joins the Central European plain, it slows and deposits silt and gravel, thus becoming an inland delta. The shallow river channel prohibits river traffic across the delta, and thus it was deemed necessary to bypass the delta with a raised canal. The canal is capable of carrying 5000 $m^3 s^{-1}$ (158 x 10^9 $m^3 yr^{-1}$), with a maximum width of 700 m, and maximum height above ground of 16 m, in some places. This intra-basin transfer canal forms part of a larger plan which will link the Danube and Rhine rivers, in order that ships can travel from the North Sea to the Black Sea (Pearce, 1994). An existing navigable canal is located between the Main - a tributary of the Rhine River - and Danube rivers (Figure 2.24; Table 2.18). This canal is also used for the transfer of up to 3 x 10^9 $m^3 yr^{-1}$ water for consumptive use within the Main River catchment (Mantel, 1978).

Table 2.18 IBT schemes of northern and central Europe.

Country	Scheme	Purpose	Donor	Recipient	Annual Volume Transferred ($10^6 m^3 yr^{-1}$)	Average Transfer Rate ($m^3 s^{-1}$)
Slovakia/ Hungary	Danube Diversion	navigation	Danube	Danube	158 000	5000
Germany	Danube-Main Scheme		River Danube	Main River (Rhine River basin)	3 000	15
Greece	Acheloos Diversion	irrigation	Acheloos	Plains of Thessaly	-	-

An IBT proposal in Greece would lead to the diversion of water from the Acheloos River, which flows into the Ionian Sea on the west coast of Greece, over the Pindus Mountains to the Plain of Thessaly on the eastern side of the mountains (Pearce, 1993b) (Figure 2.24; Table 2.18). The Acheloos is the largest river in Greece. The IBT would provide irrigation water to 2000 km^2 of rice, cotton and tobacco crops.

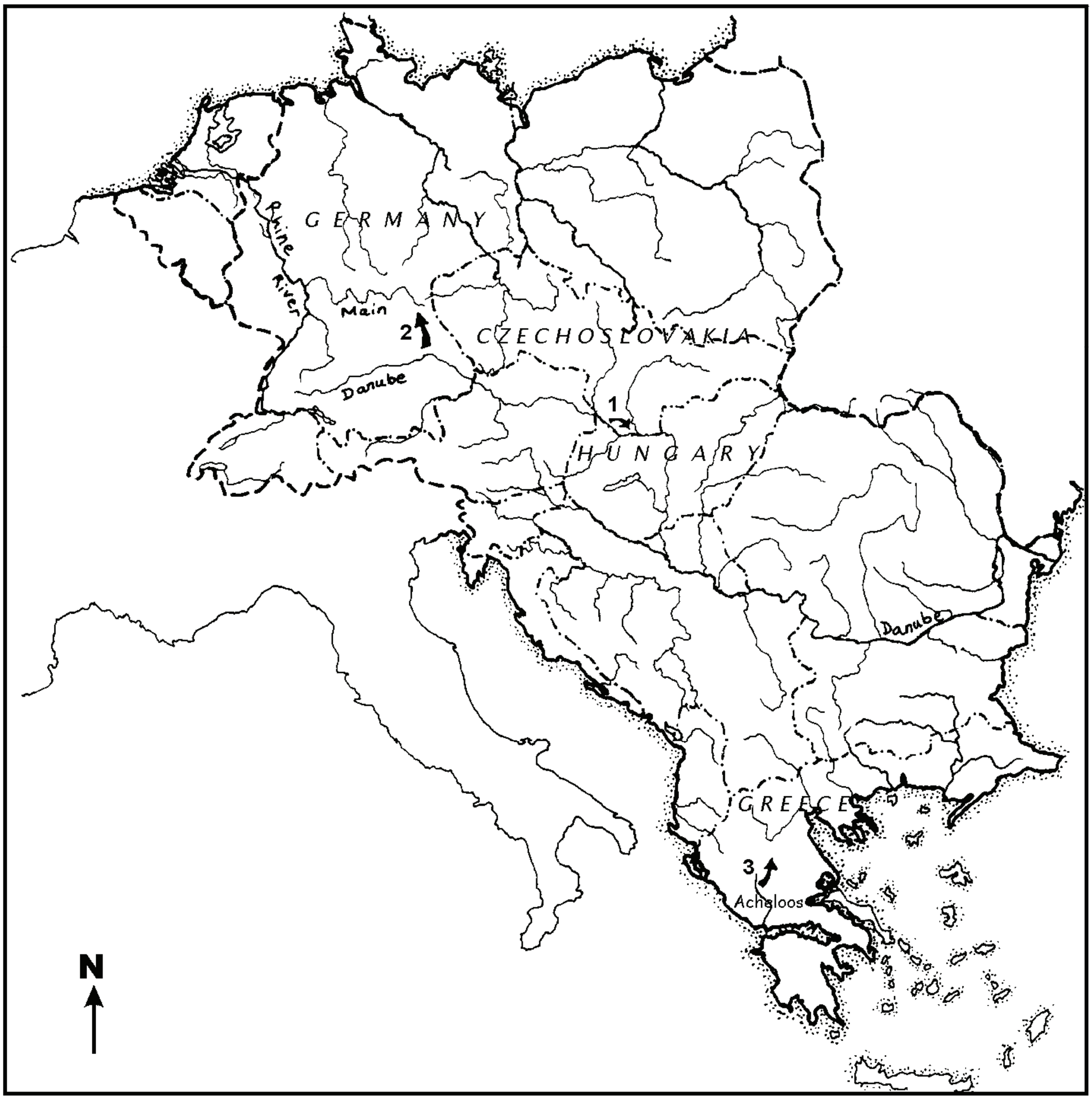


Figure 2.24 A map of central and northern Europe, showing the IBT schemes described in the text. 1, Danube Diversion (Slovakia/Hungary); 2, Danube-Main Scheme (Germany); 3, Acheloos Diversion (Greece).

2.5.3 Southern Europe

Morel (1978) has analysed the state of French IBTs, where the main reasons for transfer are hydro-electric power production, irrigation, and urban supply. The “Eaux de la Neste et de la Garonne” is primarily an inter-catchment transfer, but also involves an IBT from the Cap-de-Long Reservoir (Garonne River basin) to the Le Gave de Pau River (a tributary of the Adour River) for supply to a hydro-electric power generating unit (Figure 2.25; Table 2.19). The “Eaux du Basin Artois Picardie” involves two small IBTs from the Escaut and Canche river basins to the Lys River (Figure 2.25; Table 2.19). Both are used for urban water supply. Finally, the “Eaux de la Durance et du Verdon” involves transfer out of the Durance (Rhône River basin), *via* canals, to the urban industrial areas of Marseilles and Toulon in southern France (Figure 2.25; Table 2.19).

Table 2.19 A list of IBT schemes in Southern Europe.

Country	Scheme	Purpose	Donor	Recipient	Annual Volume Transferred (10^6 m^3 yr^{-1})	Average Transfe r Rate (m^3 s^{-1})
France	Eaux de la Neste et de la Garonne	hydro-electric power	Garonne River	Le gave de Pau River (tributary of the Adour River)	-	-
France	Eaux du Basin Artois Picardie	municipal supply	Escaut and Canche rivers	Lys River	-	-
France	Eaux de la Durance et du Verdon	industry and municipal supply	Durance River (Rhone River basin)	Marseilles/Toulon area	-	-
Spain	Tajo-Segura Transfer	general supply	Tajo River	Segura River	100 - 350	33

Spain has a substantial imbalance in its rainfall distribution pattern, with the majority of the Mediterranean basins (rivers flowing south) experiencing water shortages. In addition this area not only houses one third of the population, but also possesses the richest agricultural land. García De Jalón (1984, 1987) has reviewed the development of Spanish water resources. Major cities, such as Madrid, Barcelona, Bilbâo and Sevilla are supplied by water transfers. Water development projects are also used to provide hydro-electric power (28% of total electricity production), and although this accounts for 60% of the stored water, potable and agricultural supply take precedence when required. Since 1988, all water development projects in Spain require compulsory environmental impact assessments, although, as García De Jalón points out, human needs will still take precedence over ecological requirements for water. An IBT, diverting between 100 and 350 x 10^6 m^3 yr^{-1} of water over 286 km from the Atlantic River basin of the Tajo to the Mediterranean river basin of the Segura is the most important in this region (Figure 2.25; Table 2.19). The potential transfer capacity of the scheme is 1 x 10^9 m^3 yr^{-1} - 10% of the total run-off from the Tajo River. Operational since 1979, it has permitted a 150% increase in irrigated land (220 000 ha).

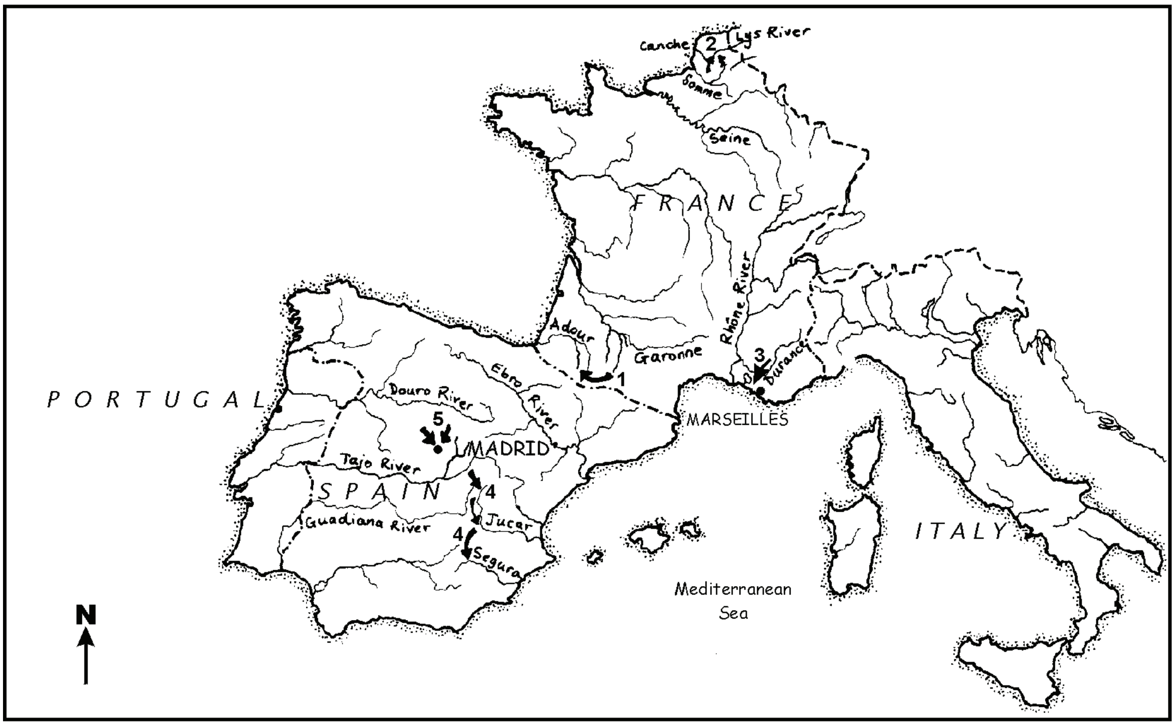


Figure 2.25 The IBTs of Spain and France. 1, Eaux de la Neste et de la Garonne (France); 2, Eaux du Basin Artois Picardie (France); 3, Eaux de la Durance et du Verdon (France); 4, Tajo-Segura Transfer (Spain); 5, transfers to Madrid.

3. ECOLOGICAL EFFECTS OF IBTS

3.1 Introduction

In order to focus on the ecological effects (physical, chemical and biological) of IBTs, it is important to identify the major differences between the effects of IBTs and the effects of river regulation by dams. Most of the literature which deals with the effects of river regulation on the ecological functioning of rivers, describes the effects of impoundments and, some workers define river regulation as impoundment (Boon, 1988). In many cases, water transfers require the impoundment of rivers and these reservoirs are often draw-off points from donor systems, as well as the storages for transferred water on recipient systems. The consequences of transfer schemes, however, are more complex, and their effects require specific attention (Day, 1985). While the ecological effects of IBTs in a donor catchment are largely similar to those that result from river regulation by dams, effects that are unique to IBTs are manifested at the catchment scale, where differences in water quality and biotic assemblages between catchments assume importance, particularly in the recipient catchments and along transfer routes (Alabaster, 1976; Snaddon and Davies, 1997, 1998). For example, the rivers in South Africa can be divided into management regions based on their water chemistry (Day and King, 1995; Day and Dallas, 1996; Day *et al*., 1998) and, thus, the transfer of water between water quality regions could affect the water chemistry of the recipient systems. In the same vein, recent efforts in South Africa to determine biological regions according to distributions of riparian vegetation, fish and riverine macroinvertebrates, have led to the description of 18 bioregions (Eekhout, 1996). Thus, the transfer of water across bioregional boundaries is likely to have effects on the biota of the receiving catchments (see Section 3.4, and also Snaddon and Davies, 2000).

The nature of the components of an IBT will influence the extent of its effects on the environment (Snaddon and Davies, 1998). Because of the wide variety of IBTs worldwide, these components can only be categorised in very broad terms according to the following criteria:

Type of donor. The donor is usually a river or stream that has been impounded, or which has a diversion weir below the drawoff point. In the case of the impoundment, the transfer tunnel inlet is generally situated at variable depths within the reservoir. In some cases, however, water is transferred from groundwater systems.

Type of recipient. In most cases, the recipient is a river or stream, but may also be an impoundment.

Type of transfer route. Several types of transfer route are employed for IBTs (Figure 1.2) - for example **pipes**, above or below ground; **canals**, open or closed; and **natural water courses.** An additional transfer route not illustrated in Figure 1.2 involves the use of **aquifers.**

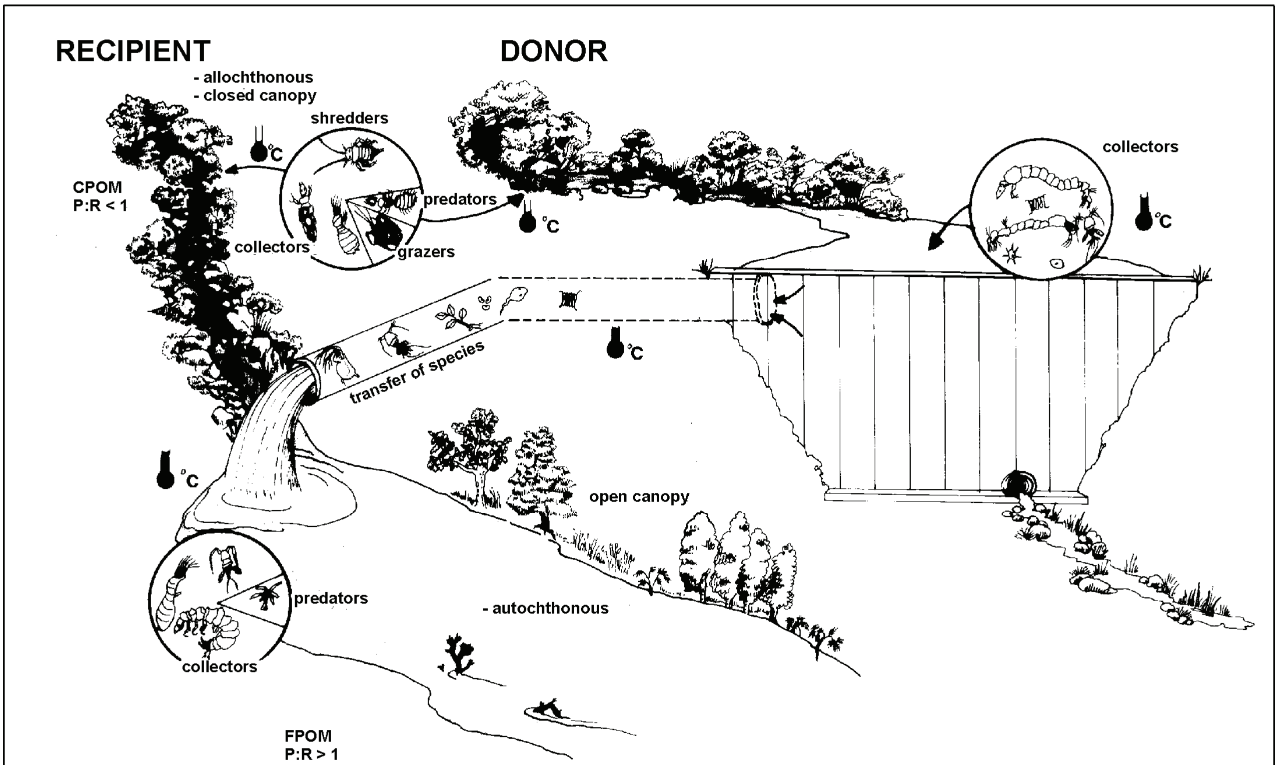
Operational criteria. The operational criteria of IBTs refers to the type and timing of release, and the volume and rate of water transfer. These criteria have significant influences on the aquatic systems affected by an IBT (e.g. Boon, 1988; Davies *et al*., 1992). The most common type of release is from the outlet of a tunnel, pipeline or canal. The release is commonly under pressure due to pumping or gravity. The timing of release is of great significance for the biota of the aquatic systems concerned, and can be seasonal or aseasonal, constant or pulsed, or combinations of these (see Figure 1.1, Chapter 1).

Furthermore, IBTs may involve adjacent river basins, or basins with a very wide geographical separation, crossing biogeographical and even international boundaries. In all of these cases, the transfers of water will lead to alterations of the basin or basins involved, irrespective of their nature. A section of a river, or an entire river basin, becomes the donor of water, while the other becomes the recipient of that water, and a myriad attendant changes take place: water losses or additions, water quality changes, alterations in physical properties of channels, temperature regimes and so on, as well as the transfer and mixing of organisms.

Figure 3.1 illustrates some of the ecological consequences of an inter-basin transfer from the middle reaches of an impounded donor river to the upper reaches of a receiving system. Over and above the well-known effects of river regulation caused by impoundments (e.g. Ward and Stanford, 1979, 1983; Petts, 1984; Petts *et al.*, 1989; Lillehammer and Saltveit, 1984; Craig and Kemper, 1987), IBTs have additional, often severe, effects.

The receiving river frequently undergoes massive, and relatively permanent, geomorphological changes, due to almost continuous discharge from the donor system. Water of different quality is introduced into a recipient, resulting in a flow and chemical regime that is often significantly different from the natural situation. As illustrated in Figure 3.1, the impoundment of a donor system will alter water quality conditions in the recipient reaches from those characteristic of a lotic system, to those of a lentic system, without the presence of an actual impoundment structure in the recipient. For example, water that is warmer than that of the recipient might be discharged from a donor impoundment, leading to alterations in temperature below the outlet (Figure 3.1). Furthermore, lentic taxa are likely to be transferred through an IBT tunnel and released into the recipient, thereby altering the availability and nature of the food source for benthic invertebrates and fish (Figure 3.1). Consequently, the composition of the biotic communities encountered below an IBT is likely to be different to that further upstream. For example, the increased organic matter introduced into a recipient as the result of a water transfer from an impoundment will lead to an increased abundance of taxa of the collector functional feeding groups (e.g. Vannote *et al.*, 1980), such as the filterers (Figure 3.1). Alterations in environmental conditions in a recipient river could lead to this system becoming suitable for the establishment of taxa that previously could not occur there (e.g. Chutter, 1991). Invertebrates are fairly rapid colonisers of newly available, suitable habitat, and the adult stages of many riverine insect taxa are strong fliers. Thus, inter-basin movement of such taxa cannot be ignored, and, in some cases, hybridisation with local populations could occur.

Figure 3.1 A summary of some of the biological effects of an IBT from an impoundment on the middle reaches



of a donor river, to the upper reaches of a recipient. Thermometer symbols represent changes in temperature, which is cooler in the headwaters, and warmer in the impoundment and downstream of the IBT outlet. P:R is the production:respiration ratio, and the invertebrates drawn in the circles represent the functional feeding groups that are expected to dominate in these systems. CPOM = coarse particulate organic matter; FPOM = fine particulate organic matter.

Recently, the breakdown of the natural biogeographical integrity of river basins caused by IBTs has been raised as an issue (De Moor, 1991; Davies *et al.*, 1992). The potential for major genetic transfers is undoubtedly a major source of concern, especially in the light of evidence (albeit, frequently anecdotal) that various invertebrate, plant and fish species have indeed been transferred between basins through IBT tunnels and pipelines (see Section 3.4). As far as we know, on a global basis there have been no successful mechanisms that have prevented the transfer of organisms through IBTs.

An increasing scientific and public awareness of the ecological and environmental effects of large-scale engineering developments has resulted in IBTs being brought to the attention of the scientific community, particularly where biogeographical barriers are broken down or breached, where water quality is affected, reduced flow conditions occur and where high ecological costs are incurred. The following sections summarise the work that has been done on the ecological effects of IBTs world-wide. The geographical location and technical details of IBT schemes referred to in this chapter are provided in Chapter 2, and the relevant section and figure are given in parentheses. Each major section in this chapter (and Chapter 4) has been summarised in table form.

3.2 Physical and Geomorphological Effects

3.2.1 Water Quantity and Flow Patterns

The main aim of water transfers is often to supply a continuous and reliable source of water, either throughout the year, or for a season. Thus, a recipient river will almost invariably lose its natural flow patterns, changing possibly from an intermittent or seasonal system, to one that is perennial. Richards and Wood (1977) looked at the hydrological effects of IBTs in the United Kingdom (U.K.), where the uses of transferred water are mostly non-consumptive (i.e. not used for irrigation or lost to the atmosphere), but generally are for use in sewage treatment processes. The transferred water, if it is not directly transferred to a river before use, reaches the recipient basin in the form of return flows, primarily from sewage works. The transfer of water thus raises the baseflow and leads to heightened flood peaks in the recipient, resulting in the more frequent occurrence of flashy floods, especially in urban areas. In some recipient catchments in the U.K., particularly in the midlands and south-east England, low flows comprise mostly imported water; the River Tame at Lea Marston, for example, is 90% effluent (Richards and Wood, 1977).
Water transfers into the River Wear, through the Kielder Water Scheme, can more than double the flow in the river, while near-bed velocities can increase tenfold in some parts of the channel. The changes in flow were recorded some distance from the IBT outlet, while the marked increases in velocity were limited to within 250 metres of the release point.

The Orange River Project (ORP) in South Africa involves a constant transfer of water from the Orange River southwards into the Great Fish River, and then the Sundays River (Section 2.1.3; Figure 2.4). Since 1977, this scheme has provided an annual volume of 350 x 10^6 m^3 yr^{-1} of water for irrigation in the receiving catchments. The primary influence of the ORP has been a 500 to 800% increase in flow in the upper section of the Great Fish River, and although the flow in the lower river remains similar to pre-transfer values, the river is now perennial as opposed to seasonal (O'Keeffe and de Moor, 1988). Similarly, the extent of flow alteration in the upper Berg River, a recipient of the Riviersonderend-Berg-Eerste River Government Water Scheme (RBEGS) in South Africa (Section 2.1.3; Figures 2.4, 2.8), can best be described in terms of the percentage increase over the discharge measured upstream of the IBT. During summer months, when the IBT is in operation for irrigation, discharges downstream of the IBT increase by a staggering 570-4400% over discharges measured upstream of the transfer on the same day (Snaddon, 1998). These summer discharges constitute substantial increases, during months when natural discharges in the Berg River are at their lowest. Thus, although water is released at a rate that does not exceed 5 m^3 s^{-1}, these alterations in flow and, consequently, width, represented a substantial disturbance to the river.

One of the largest IBTs on the Australian continent is the Snowy Mountains Scheme (Section 2.4.1; Figure 2.20), which involves a transfer of 1.1 x 10^9 m^3 yr^{-1} from the Snowy River to the Murray River system. Both donor and recipient rivers of the Snowy Mountains Scheme have been affected by the transfer. Substantial flow fluctuations have been experienced in recipient river channels as a result of hydro-electric power demand. At one of the power stations, Tumut 3, for example, releases of up to 1130 m^3 s^{-1} can be made on demand and, as a result, the construction of regulation structures on the recipient Murray River has become necessary in order to reduce diurnal fluctuations in water level, and to minimise river bank erosion (Johnson and Millner, 1978). Recipient systems in the Snowy Mountains Scheme are primarily managed as conduits for irrigation water. For example, the Tumut River is managed to maximise capacity by removing all in-channel vegetation and altering sections of the channel in order to minimise flow resistance. During the summer irrigation period, flows are maintained at bankfull capacity, which has implications for channel stability (Thoms and Walker, 1992a).

Table 3.1 A summary of the effects of IBTs on water quantity and flow patterns, as reported in the text.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Water Quantity			
Australia	Snowy Mountains Scheme	• flow fluctuations in recipient Murray River catchment; 45-99% reductions in flow in donor Snowy River	
Canada	Churchill River Diversion	• 35-fold increase in flow in the Rat River, 7-fold increase in the Burntwood River; 34% increase expected in the lower Nelson River • 75% reduction in flow in donor Churchill River	
Canada	James Bay Project	• 87% reduction of flow in the donor Eastmain River; 43% reduction in the Caniapiscau River • 2-fold increase in discharge in recipient, La Grande Rivière	
Russia	European Transfer Project (ETP) **PROPOSAL**	• PHASE I: 53% reduction in flow in donor Onega River; 43% reduction in Upper Sukhona River, with sedimentation and tributary downcutting likely • PHASE II: reduced flow in the Svir and Neva rivers • FURTHER PHASE: 40-76% reduction in flow in the Pechora River, with effects on bank stability, navigation and on floodplain ecology • OVERALL: increased freshwater input to Caspian Sea, the Sea of Azov, the Volga-Akhtuba floodplain and the Volga estuary	Project shelved
Russia	Siberia-Central Asia Project (SCAP) **PROPOSAL**	• flow fluctuations; 9-15% flow reduction in wet years and 19-31% for dry years in the Ob River; flow reductions in the Irtysch • reduced inundation of important floodplains • improved conditions in the recipient Aral Sea	Project shelved
South Africa	Orange River Project (ORP)	• 500-800% increase in flow in recipient Great Fish River, converted from seasonal to perennial system	
South Africa	Riviersonderend-Berg-Eerste River Government Water Scheme (RBEGS)	• 570-4400% increase in flow in recipient Berg River; increased width	
Southern Africa	Lesotho Highlands Water Project	• PHASE IA: substantial reductions and fluctuations in flow in donor Malibamatso River; decreased channel size of Malibamatso • FURTHER PHASES: 1 in 20 year flood equivalent expected in recipient Ash/Liebenbergsvlei system; inundation of land in recipient catchments	
U.K.	Kielder Water Scheme	• flow was doubled in the River Wear, and velocities increased tenfold in some areas of the channel	

The Snowy Mountains Scheme has caused flow reductions in the donor river, the Snowy. All of the flow above Jindabyne is diverted out of the basin, and although this only represents 15% of the catchment area, it represents 50% of the total catchment output. Mean monthly and annual runoff has decreased significantly at all stations, but the magnitude of the reduction decreases with distance downstream, from approximately 99% in the upper reaches, to 45% further downstream (Terrazolo, 1990). Similar changes to flow duration and flood frequencies have also occurred (Figures 3.3a,b). Recent studies by the Victorian Department of Water Resources graded the condition of all that state's waterways on the basis of ten factors, including substratum composition, channel stability, water quality and instream biota. The Snowy River was classed as being in poor or moderate condition throughout 95% of its length, while neighbouring tributaries were all considered to be in excellent condition. This apparent decline of the Snowy River primarily appears to be associated with the change in flow conditions due to the Snowy Mountains Scheme (Mitchell, 1990).

Similarly massive transfer schemes were proposed in Russia. These were the European Transfer Project (ETP), which involved the redistribution of water resources of northern rivers and lakes to the Caspian Sea Basin in the south, and the Siberia-Central Asia Project (SCAP), comprising the diversion of Siberian rivers southwards to the Aral Sea Basin (Micklin, 1985) (Section 2.3.1; Figure 2.16). The ETP would have resulted in a 53% reduction in the flow of one of the donors, the Onega River, at its outflow from Lake Lacha (Voropaev and Velikanov, 1985; Micklin, 1986). Furthermore, a reduction of 43% of the flow of the Upper Sukhona River, another donor system, would have led to sedimentation and tributary downcutting, resulting in difficulties for navigation and for timber rafting on the river. A second-stage diversion of water from Lake Onega (3.5×10^9 m^3 yr^{-1}) would have reduced flow in the Svir and Neva rivers, while a third stage diversion from the Pechora River of 9.8×10^9 m^3 yr^{-1} *via* the Kolva and Kama rivers to the Volga would have had a significant impact on the Pechora, thereby reducing flows below the Mitrofanovskoye hydro-electric dam by between 40 and 76%, with consequent effects on bank stability, navigation and on floodplain ecology (Voropaev and Velikanov, 1985; Micklin, 1986).

In the proposed recipient area of the ETP, the Caspian Sea, the Sea of Azov, the Volga-Akhtuba floodplain and the Volga estuary are all areas that have suffered greatly from over-exploitation of their water resources through abstraction and IBTs. In 1978, the Caspian Sea dropped 29 m to its lowest level ever, and the Sea of Azov suffered from high salinities. The deterioration of these systems could have been checked by the ETP (Micklin, 1986).

The SCAP proposal was for a larger scheme, covering a greater distance than the ETP. It was designed respectively to transfer 27.2 and 60×10^9 m^3 yr^{-1} of water in Phases I and II. The donor rivers, the Ob and Irtysch, would have been substantially reduced in volume below points of diversion, resulting in a wet-year flow reduction in the Ob at Salekhard of between 9 (Phase I) and 15% (Phase II), and between 19 and 31% for dry years. These reductions in flow, combined with unnatural flow fluctuations, would have reduced inundation of important floodplains in the Ob and Irtysch river catchments. One of the perceived benefits of the SCAP proposal was an improvement in conditions in the recipient Aral Sea basin (Section 2.3.1; Figure 2.16). The Sea has been shrinking rapidly for the last 30 years, and the cause is directly attributable to the diversion of 100×10^6 m^3 yr^{-1} from the Amudar'ya and Syrdar'ya rivers, which feed into the Aral, for irrigation of the desert regions of Kazakhstan and Uzbekistan (Micklin, 1985). Micklin (1988) has described how the Aral Sea, which lies in one of the recipient catchments of the SCAP, has decreased in area since 1960 from 68 000 to 41 000 km^2, halving its volume and dropping its level by more than 12 m (see also Williams and Aladin, 1991).

The Churchill River Diversion in Canada (Section 2.2.1; Figure 2.9) has led to substantial changes in discharge in both the recipient and donor systems. One of the recipients, the Rat River, receives an average annual transferred volume of 775 m^3 s^{-1} (24×10^9 m^3 yr^{-1}), which is approximately 35 times its normal flow, and seven times the normal flow of the next recipient, the Burntwood River. On the lower Nelson, a 34% increase in the mean annual flow was expected. Concurrently, the scheme has reduced the flow of the Churchill River at the outflow of Southern Indian Lake by 75%, from 1011 to 251 m^3 s^{-1}. The James Bay Project, an additional hydro-electric development in Canada, involves the transfer of 87% of flow in the Eastmain River (25×10^9 m^3 yr^{-1}) and 43% of water flowing in the Caniapiscau River (24×10^9 m^3 yr^{-1}), into the La Grande Rivière (Day, 1985). An additional transfer from the Sakami River in a neighbouring catchment brings a further 30 m^3 s^{-1} (0.9×10^9 m^3 yr^{-1}) into the La Grande, *via* a hydro-electric power generation unit. The total amount transferred to the La Grande is 1586 m^3 s^{-1} (50×10^9 m^3 yr^{-1}), almost double its natural flow volume.

Remaining at this massive scale of water transfer, the largest dam wall on the African continent is the Katse Dam, which is the major impoundment of Phase IA of the LHWP in southern Africa (Section 2.1.3; Figure 2.4, 2.7). If the first phases (IA and IB) of this scheme are completed as planned, it will involve the transfer of 30 m^3 s^{-1} (0.9×10^9 m^3 yr^{-1}) from the headwaters of the Orange River in Lesotho, into a tributary of the Vaal River, in South Africa (Department of Water Affairs, 1985). A major consequence of Phase IA of the LHWP will be a substantial reduction in flow and changes to the natural flow regime of the donor river, the Malibamatso. The 182 m-high Katse Dam will store 3.3 times the mean annual runoff (MAR) of the Malibamatso catchment, which is an unusually large storage (Chutter, 1993). The river channel is expected to decrease in size due to the diversion of water, with bankfull discharges only occurring when the Katse Dam spills during heavy summer rains. The final transfer volume for the LHWP was initially calculated at 70 $m^3 s^{-1}$ (2.2 x 10^9 $m^3 yr^{-1}$); this volume approaches the present 20-year-flood discharge in the recipient Ash River, a tributary of the Vaal River. Lower down the system, after the Ash joins the Liebenbergsvlei and then the Wilge River, the combined 'natural' flow of these last two rivers is predicted to exceed the flow due to the transfer scheme in only 11% of the months in a 55-year synthetic flow record (Chutter, 1993). In places, the augmented flow in the Liebenbergsvlei River will exceed the capacity of the channel, and some inundation of land will occur. Currently, the costs of transporting the water to its point of use, through an underground pipeline, are being evaluated in order to avoid the consequences of increased flow in the Ash and Liebenbergsvlei rivers (E. Van den Berg, Department of Water Affairs and Forestry, personal communication, October, 1997).

3.2.2 Erosion and Geomorphological Changes

In terms of natural geomorphological change on a large scale, inter-basin water transfers have been a fairly common phenomenon over time in various parts of the globe. In southern Africa, for example, river capture or piracy has played an important role in the development of drainage systems (Moon, 1991). The resultant geomorphological alterations are substantial, where one river channel is abandoned and another augmented. Such naturally occurring IBTs provide clues to the consequences of human-made water transfers (Moon, 1991).

Table 3.2 A summary of the effects of IBTs on erosion and geomorphology of riverine systems.

Country	Scheme	Effects (actual and potential)
Erosion and Geomorphology		
Australia	Nymboida River-Blaxlands Creek Scheme	• erosion of channels in recipient Blaxland Creek • river rehabilitation measures at a cost of A $0.5 million
Australia	Shoalhaven-Wingecarribee Diversion	• inundation of land in places; bank and bed erosion; overbank or in-channel sedimentation in places
Canada	Long Lake and Ogoki diversions	• rapid erosion in diversion channels • erosion in recipient Little Jackfish River
South Africa	Mooi-Mgeni Transfer **UPGRADE**	• some reaches of the recipient Mpofana River likely to erode further
South Africa	Amatole Scheme	• bank and bed erosion in recipient
Southern Africa	Lesotho Highlands Water Project	• erosion, stream-bed armouring, and transport of sediment downriver in the Malibamatso (donor) and Ash/Liebenbergsvlei rivers, as a result of settling of sediment in Katse Reservoir
U.S.A.	Santee-Cooper Diversion	• increased sediment load in the Cooper River led to decreased navigational capacity, and increased ship-channel maintenance costs in harbour

As stated earlier, IBTs generally lead to changes in the quantity of water in the donor, recipient and transfer system and, thus, to changes in sediment type, transport and retention (e.g. James, 1991). For example, the increased flows and increased frequency of high flows capable of transporting sediment, due to IBTs, often lead to bank and bed erosion in recipient systems. This has been found on a fairly small scale in the U.K. (Richards and Wood, 1977), while rapid erosion has been recorded and continues to be a problem in diversion channels, such as the Aguasabon, used by the Long Lake and Ogoki diversions in Canada (Day *et al*., 1982; Day, 1985) (Section 2.2.1; Figure 2.9). Flows in a recipient, the Little Jackfish River, increased from 4 to 118 $m^3 s^{-1}$ with mean peak flows of 311 $m^3 s^{-1}$ as a result of the Ogoki Diversion (Day *et al*., 1982). This resulted in substantial erosion of the river channel.

The diversion and re-diversion of the Santee and Cooper rivers, South Carolina (USA), provide unique, long-term case studies of the geomorphological implications of water transfer (Section 2.2.2; Figure 2.13). In 1942, the Santee-Cooper Project was implemented to divert approximately 88% of Santee River flow into the Cooper River. As a result, mean annual discharge of the Cooper River increased from 2 $m^3 s^{-1}$ to 442 $m^3 s^{-1}$ (Cooke and Eversole, 1994). An increased sediment load caused increased shoaling in navigation channels and increased costs associated with ship-channel maintenance in Charleston Harbor. The Santee-Cooper Re-diversion Project, completed in 1985, was created to reduce the sediment load by re-diverting approximately 71% of Cooper River flow back into the Santee River.

The Mpofana River, a tributary of the Mgeni River in Kwazulu/Natal Province in South Africa, is due to receive an increased transfer of water from the Mooi River, due to the upgrading of the Mooi-Mgeni Transfer Scheme (Section 2.1.3; Figure 2.4). Sections of this river are characterised as unconfined channel flowing through wide or restricted floodplains (Heritage, 1995), and it is predicted (albeit based on limited information) that these reaches are likely to be susceptible to erosion. The substratum is largely fine sand and silt and the banks are composed of alluvium, often forming vertical cliffs on meanders (Heritage, 1995), and elevated flows will invariably cause geomorphological change in this system. Still in South Africa, the recipient stream of the Amatole Scheme, Eastern Cape Province (Section 2.1.3; Figure 2.4), was subjected to test releases which did not exceed 1 $m^3 s^{-1}$, but which led to considerable bank and bed erosion. As a consequence, the roots of riparian tree species were exposed (O'Keeffe and Ashton, 1991).

The downstream reaches of the Malibamatso River, donor to the LHWP in southern Africa (Section 2.1.3; Figure 2.4), will receive sediment-free water from Katse Dam, due to the settling out of finer sediments, which will in turn and in all likelihood, result in erosion, stream-bed armouring, and the transport of sediment down the river (Chutter, 1993). Similarly, and in addition to changes in flow volumes in the recipient Ash River, the river will receive water that is clear and which will carry little sediment (Chutter, 1993). Accordingly, geomorphological consequences for the Ash River may be considerable, with increased erosion and armouring of the streambed.

Detailed studies of the geomorphological changes associated with IBTs have been performed on two Australian schemes, and a synthesis of this information is provided here by Dr Martin Thoms (Co-operative Research Centre for Freshwater Biology, University of Canberra, ACT, Australia). The Nymboida River-Blaxlands Creek Scheme in Australia has had a significant impact on river channel morphology in the recipient, Blaxland Creek (Section 2.4.1; Figure 2.20). The upper reaches of this river are confined within a narrow valley, which thus allows limited floodplain development. However, approximately 10 km downstream of the transfer, the river meanders through a relatively wider valley-floor trough, which provides extensive floodplain surfaces. It is in this section of the catchment that extensive river channel adjustments have occurred as a result of the water transfer. The earliest record of river channel erosion in this basin was in 1928, four years after completion of the scheme. Photographs taken in the late 1930s show evidence of severe bank erosion, and a major proportion of the riparian vegetation appears to be missing. A survey of the bank erosion problem in 1973 recorded that up to 60% of the river banks had significant erosion problems with a recession rate of over 1 m yr^{-1}. Between 1930 and 1973 the local council opted to recompense landholders based on an amount per unit of land lost to river erosion. Annual channel surveys provided the basis for this calculation. Whilst the council will not disclose the actual amount of compensation paid to riparian landholders, estimates range from A$8 to A $20 million. Due to financial problems, the local council, along with the New South Wales Department of Water Resources, undertook a major river management program to prevent further loss of land. This involved an extensive 'river training' exercise which included:

- stream re-alignment to guide flows away from and past eroding banks;
- the construction of wire mesh fences along each alignment, that are secured to the river bed by steel piles, and
- planting of dense thickets of introduced willows to encourage sediment deposition and provide protection after the deterioration of the wire mesh.

These measures, undertaken between 1973 and 1986, cost in excess of A $0.5 million.

Evaluation of the river training measures was undertaken in 1990. It was noted that lateral bank erosion was only occurring in minor locations and that most areas of severe erosion had stabilised. Riparian vegetation was reported to be flourishing along the entire length of the river, although this comprised willows and other exotic species. Minor maintenance works on the river banks are currently performed at regular intervals to prevent the accumulation of snags (in-channel woody debris) and to prevent flow diversions against channel boundaries. Whilst the bank protection works have been perceived to be successful, bed erosion has occurred. In some river reaches, the bed has been eroded up to 4 m and this is threatening to undermine the bank protection works.

Even in the light of massive channel instability problems, the local water authority is still considering an increase in the volume of water transferred, in order to meet increasing hydro-electric power demands.

Recent studies on the Shoalhaven-Wingecarribee Diversion, also in Australia (Section 2.4.1; Figure 2.20), have focused on the impact of water transfers on channel stability and water quality in the recipient Wingecarribee River. The Wingecarribee River is approximately 28.5 km long and has a highly variable channel morphology, as the river is incised into a valley with a wide range of soil types. Upstream of Berrima Weir, the Wingecarribee River flows through a floodplain and a series of river terraces that are derived from the Triassic Liverpool Subgroup of the Wianamatta Group (mainly shales), Tertiary basalt and Tertiary clayey sands. In the Berrima Weir pool, the Wingecarribee River has cut through the relatively soft shales of the Liverpool Subgroup into highly resistant, quartzitic sandstone of the Triassic Hawkesbury Sandstone Series. Hence the valley is narrower and steeper than upstream. Further downstream, the river flows in a very deep, narrow valley cut into a range of sedimentary, metamorphic and igneous rocks. Consequently, the river's ability to convey controlled releases of up to 1×10^6 m^3 day^{-1} varies from place to place. In some reaches the flow is contained within the channel, while in others, it inundates large areas of adjacent land. Where flow is contained within narrow channels, flooding is not a problem, but bank and bed erosion, as a result of the higher flow velocities, are evident. Overbank flow in the narrower sections of river leads to lower flow velocities in the channel, with the consequent possibility of overbank or in-channel sedimentation.

Before the implementation of the water transfer scheme, streamflow in the Wingecarribee River was controlled by the large Wingecarribee Swamp, now partly submerged under Wingecarribee Reservoir. Storage of water in this reservoir commenced in September 1973, and the dam was completed in August 1974. Flow regulation has reduced downstream flood peaks but other hydrological effects of the IBT remain undocumented. In order to assess the impacts on the Wingecarribee River that are specific to the IBT, trial water releases occurred between 5 September and 2 October 1991. Discharges increased from a minimum of 0.05 m^3 s^{-1}, to a maximum of 12.8 m^3 s^{-1}. The release had a step-function shape with discharge increasing from approximately 1.2 to 6.9 m^3 s^{-1}, in 1.2 m^3 s^{-1} increments, and then increasing from approximately 6.9 to 11.6 m^3 s^{-1}, in 2.3 m^3 s^{-1} increments. After the peak, releases were reduced to approximately 7.6 m^3 s^{-1} for two days before being reduced to 0.15 m^3 s^{-1}. The peak discharge was maintained for four days. The travel times for the release increments between each gauging station varied from about 13 hours at 2.3 m^3 s^{-1} to about five hours at 11.6 m^3 s^{-1}.

Chessman *et al.* (1992) analysed the turbidity and suspended solids data collected at various stations along the river during the trial release. Turbidities were generally low (< 10 Nephelometric turbidity units (NTU)) with isolated peaks up to 20 NTU. Suspended solids concentrations were low, generally less that 10 mg l^{-1}. Although the estimated total suspended solids loads for the release were low, ranging from 40 to 98 tonnes, they do demonstrate that sediment was being progressively entrained with increasing distance from the dam, without a corresponding increase in discharge. Sediment availability therefore constrains sediment transport within the reach. This implies an erosion potential which is not being achieved because of the erosion resistance of the bed and banks of the channel.

Data collected during the trial release raised several issues concerning the effects of water transfers on recipient river channels. These are as follows:

1. Long-term releases at channel capacity will have a profound influence on aquatic and riparian vegetation. Changes in vegetation can impact significantly on stream hydraulics and channel morphology. Two opposing responses are likely as the result of prolonged operational releases:

    - Some vegetation types will respond to inundation or partial inundation by prolific growth. Examples of this response would include willows and other exotic trees and aquatic plants. Some pasture grasses, weeds and noxious plants are likely to respond to the 'irrigation' by growing vigorously as waters recede.
    - Other vegetation types will experience severely reduced growth rates, or will be killed as a result of prolonged inundation. Examples include grasses and most small plants. Even some native riparian tree species can be killed if completely inundated for prolonged periods.

    The most profound effects will result from killing or curtailing vegetation by inundation. An operational release strategy which provides for occasional long durations of artificially high flows will result in an unstable riparian vegetation regime. Loss of vegetation from bank or floodplain could alter channel hydraulics and leave large areas vulnerable to scour, and a major morphological response is likely. The channel will widen by undercutting, or through direct attrition of the banks. Existing erosion sites will be exacerbated and new erosion sites will develop.

Furthermore, watering from IBT releases may lead to the proliferation of some species of in-channel vegetation, and encourage their spread into other areas of the channel. The encroachment of instream vegetation will reduce in-channel capacity, increase overbank flows and encourage in-channel sedimentation. There are some sections of river channel in Australia, for example, that are already severely constricted through the invasion of willows and other exotic trees. Furthermore, noxious plants and weeds are likely to become a problem following inundation of areas of floodplain or river bank. Where the existing cover is killed or retarded by inundation, noxious plants will colonise as the water recedes.

2. Bank erosion did occur at a number of sites along the Wingecarribee River, mainly by entrainment and sloughing of material off the bank face. In most rivers, bank erosion rates are low and are associated with particular factors, such as alignment instability or bed degradation. However, there is the possibility that long durations of flow at, or at about, bankfull, may trigger extensive bank instability. The mechanism for such instability would be:

   - loss of protective vegetation from the bank or verge as a result of long-term inundation;
   - long-term saturation of bank material followed by drawdown and collapse;
   - long-term attrition of material from the face of the bank, or
   - bed-deepening associated with exhaustion of sediment supplies.

3. There were indications that the channel was starved of sediment in some locations, particularly towards the upstream end. This evidence includes bedrock and clay exposures in the channel bed, absence of deposition in flow separation envelopes, armouring of riffles, and the occurrence of minor races in the channel. This evidence was supported by suspended sediment measurements.

   The effect of long durations of bankfull flows is difficult to predict. Prolonged clear water releases may exhaust sediment supplies in the channel near the dam and trigger degradation in vulnerable areas downstream.

4. Cutoffs occur when erosion forms a new shorter channel across the neck of land between two, usually adjacent, channel bends. The channel in the bend is abandoned in favour of the new short cut. There were a number of imminent cutoffs noted on the Wingecarribee. Potential cutoffs will be particularly vulnerable to long duration flows at or above bankfull because:

   - flow across the neck of a loop cascades back into the channel downstream encouraging headward erosion of the neck; and
   - prolonged inundation of vegetation across the neck may reduce resistance to erosion along the overbank flow path initiating scour.

   A cutoff can have significant effects upstream and downstream of the cutoff location. Erskine *et al*. (1995) have outlined the geomorphological effects of cutoffs as a shortening of stream length, with a consequent increase in slope and a decrease in resistance to flow, both of which result in localised but significant increases in flow velocity. River response to increased flow velocities caused by cutoffs includes the upstream progression of bed erosion, downstream deposition and channel widening (Erskine *et al*., 1995).

5. Areas of sedimentation were associated with backwater effects from the various weirs along the Wingecarrabee River. At these locations, sedimentation and associated proliferation of vegetation have reduced channel capacity to the extent that the trial releases caused sufficient overbank flooding to be of concern to landowners.

   Deposition in these zones is initiated by flow deceleration under the influence of the downstream impoundment. Sediment in transport is dropped progressively as the transport capacity of the flow decreases. In time, vegetation growth provides further flow resistance, increasing the backwater effects, and deposition progresses upstream.

With IBT releases, increased duration of flows capable of mobilising sediments will increase total volumes of sediment deposited in the depositional zones, at least until supplies of sediment from upstream are exhausted. Localised reductions in channel capacity would be expected to worsen, leading to increased overbank flooding.

3.2.3 Groundwater Resources

In many cases water is drawn from groundwater sources, either to feed transfer schemes directly, or even to replenish supplies that have been over-utilised. In southern Africa, for example, Namibian farmers have reported severe water-table depression. It is likely that this will be exacerbated by the Karstveld borehole scheme, that supplies water to the Eastern National Water Carrier (ENWC) (Petitjean and Davies, 1988a, b; Davies *et al*., 1992, Davies *et al*., 1993a) (Section 2.3.1; Figure 2.4). Severe water-table depression in the Karstveld region of Namibia has already occurred, and the situation is currently being assessed in order to ascertain the extent to which this unique veld type will be damaged (Petitjean and Davies, 1988a, b). Another example can be drawn from Israel where, in the 1970s, rainfall was inadequate to provide sufficient runoff to the rivers flowing into Lake Kinneret (the Sea of Galilee), which is the source of water for the National Water Carrier that feeds Tel Aviv and the Negev region (Overman, 1976; Gavaghan, 1986) (Section 2.1.1; Figure 2.2). Exacerbating this water crisis, is the fact that the water-table to the north and south of the country is sinking to very low levels due both to over-abstraction and to inadequate recharge. Israeli engineers have attempted to solve this problem by pumping water out of Lake Kinneret and into the depleted wells in the north. This water flowed underground and along an aquifer that acted as a natural conduit extending down to the drier southern region, and consequently, water levels rose in the southern wells.

Excessive groundwater abstraction in the vicinity of Mexico City has resulted in more than 9 m of land subsidence, with consequent poor quality water and drainage problems necessitating a new deep drainage system (Garduño, 1985). In order to replenish supplies, groundwater is abstracted from the neighbouring Lerma Basin for transfer to Mexico City (Section 2.2.2; Figure 2.14). Consequently, excessive abstraction from the Lerma Basin has resulted in land subsidence and the drying up of lakes.

A further problem linked with IBTs is the seepage of water from unlined transfer canals. This would be a likely consequence of two proposed transfers, the East Route in China (Changming *et al.*, 1985) (Section 2.3.2; Figure 2.17), and the SCAP in Russia (Gorodetskaya, 1982) (Section 2.3.1; Figure 2.16). In Russia, the 2000 km unlined transfer canal from Tobol'sk in Western Siberia to the Amudar'ya in Central Asia (the transfer route for SCAP) would have raised groundwater levels in areas adjacent to the canal.

Table 3.3 The effects of IBTs on groundwater resources, as reported in the text.

Country	Scheme	Effects (actual and potential)
Groundwater		
China	East Route **PROPOSAL**	• leakage of water from canals likely to raise groundwater levels
Israel	National Water Carrier	• water transferred through aquifers as an alternative to surface transfer through NWC
Mexico	Lerma Basin abstractions to Mexico City	• land subsidence and drying up of lakes
Namibia	Eastern National Water Carrier	• water table depression in Karstveld area
Russia	SCAP **PROPOSAL**	• leakage of water from canals likely to raise groundwater levels

3.2.4 Seismic Activity

A recent concern in southern Africa is reservoir-induced seismic activity, which has occurred as the result of filling of the Katse Reservoir in Lesotho, donor impoundment to the LHWP (Section 2.1.3; Figure 2.4). The reservoir commenced filling towards the end of 1995, and a series of seismic events was almost immediately triggered. At 29% capacity, at least three events greater than magnitude 2.5 (2.7, 3.0 and 3.5) were recorded, the last of which caused a 1.3 km-long crack in the earth in the Mapeleng region in April 1996, less than six months after Katse commenced filling (Hendron and Gibson, 1996). Current predictions estimate that seismic events could continue and may reach magnitude 4 to 4.5 on the Richter Scale as the reservoir continues to fill. Katse (built) and Mohale (under construction) reservoirs, both large donor impoundments of the LHWP, are in an area of high seismic activity (e.g. Hartnady, 1985). Katse Dam is designed to withstand events up to 6.5 on the Richter Scale (LHDA Press Release, 19 February, 1996), however, the seismic strengths of the transfer tunnels northwards to the Vaal River, South Africa, appear not to have been determined. Earthquake damage to transfer tunnels and other LHWP infrastructure will have severe effects on water supply, and would present a potential threat to human life and damage to property, not only in Lesotho, but also in the provinces of KwaZulu/Natal, Free State and Gauteng (Davies, 1996).

Table 3.4 The effect of an IBT on seismic activity.

Country	Scheme	Effects (actual and potential)
Seismic Activity		
Lesotho	LHWP	• reservoir-induced seismic activity in Katse Reservoir area (Phase IA)

3.3 Chemical Effects

3.3.1 Water Quality

The transfer of water from one area to another often leads to alterations in the water chemistry of the recipient basin. In arid lands particularly, problems often result from changes in conductivity. For example, the conductivity of Lake Texoma, donor to the IBT scheme which transfers water to Lake Lavon (Section 2.2.2; Figure 2.12), is generally about 1500 $\mu S\ cm^{-1}$ because of the relatively saline Red River. The water is intermittently pumped into the comparatively freshwater Lake Lavon by way of Sister Grove Creek where conductivities rarely exceed 300 $\mu S\ cm^{-1}$ (Schorr *et al.*, 1993). However, Schorr *et al.* (1993) concluded that short-term pumping operations did not significantly alter conductivity in Lake Lavon.

In Asia, the diversion of 100 x 10^6 m^3 yr^{-1} from the Amudar'ya and Syrdar'ya rivers for irrigation of the desert regions of Kazakhstan and Uzbekistan, has resulted in salinity values in excess of 27 g l^{-1} in the Aral Sea into which these rivers feed (Micklin, 1988) (Section 2.3.1; Figure 2.16). On the other hand, the ORP in South Africa (Section 2.1.3; Figure 2.4) has enabled dilution of the salinised Great Fish River (recipient), particularly with respect to sodium, chloride, magnesium and sulphate ions, but in the lower river there appears to be no significant reduction in any of the chemical parameters measured (O'Keeffe and De Moor, 1988). Salinisation has been, and still is of serious concern to agriculture in the areas to which water will be transferred by the East Route in China, as well as along the transfer route (Section 2.3.2; Figure 2.17). More recently there has been a reduction in salinisation, but care must be taken to avoid recurrence of the problem (Huanting *et al*., 1983).

Table 3.5 A summary of the effects of IBTs on water quality.

Country	**Scheme**	**Effects (actual and potential)**
Water Quality		
Australia	Lower Murray River transfers	• increased salinity and turbidity in all recipient reservoirs in Adelaide/Whyalla area
Australia	Snowy Mountains Scheme	• water in the Snowy River is 6°C cooler than recipient Murray River water
Canada	Churchill River Diversion	• decrease in water temperature in Southern Indian Lake, a receiving water body
China	East Route **PROPOSAL**	• salinisation of recipient soils • possibility of transfer of pollutants from donor to recipient catchments
Namibia	ENWC	• growth of filamentous algae in open canals likely to cause deteriorations in water quality
North America	NAWAPA **PROPOSAL**	• donor waters cooler than recipient waters
Russia	Amudar'ya and Syrdar'ya diversions	• increased conductivity in Aral Sea
Russia	ETP **PROPOSAL**	• increased concentration of pollutants in donor Onega and Sukhona rivers; increased pollutants in Gulf of Finland due to diversion of flow from the Neva River
Russia	Severskiy Donets-Donbas Canal	• growth of filamentous algae in open canals causes decreases in water quality
South Africa	Orange River Project	• reduction in salinities in recipient Great Fish River
South Africa	Riviersonderend-Berg-Eerste River Government Water Scheme (RBEGS)	• transfer of geosmin, a non-toxic cyanophyte exudate, from donor reservoir to the recipient Berg River, affecting flesh of rainbow trout in a downstream farm • increased pH, conductivity, total dissolved and suspended solids, sodium, magnesium, potassium and calcium cations, and sulphate and chloride anions in the recipient Berg River
Southern Africa	LHWP	• water in donor Katse Reservoir expected to be warmer in summer and cooler in winter than water in the recipient Ash River
U.K.	Kielder Water Scheme	• possible dilution of pollutants in recipient basins
U.K.	Ely Ouse to Essex Scheme	• transfer of pesticide from Ely Ouse to Essex catchment, where tomatoes were rendered unmarketable • transfer of beet factory effluent from Ely Ouse to Essex • dilution of sewage spill in a recipient, the River Stour
U.S.A.	Lake Texoma-Lake Lavon Transfer	• increased conductivity in recipient Sister Grove Creek

In Australia, the Lower Murray transfers (Section 2.4.1; Figure 2.20) have increased both salinity and turbidity of all receiving waters in the Adelaide/Whyalla region (Cugley, 1988), and the cost of salt damage to the Adelaide consumer is estimated at A \$20 million yr^{-1}, which corresponds to A \$0.70 for every litre of water pumped through the system. The influence of elevated turbidity levels on recipient systems has been studied by

Cugley (1988). Time-series analyses of data for the period 1948-1986 have indicated that in Mount Bold, one of the larger storages in the Adelaide region, turbidities increased periodically by 150 NTU (Nephelometric Turbidity Units) with the onset of pumping Murray water, and that elevated levels persisted for up to 4 months after the pumping ceased. The ecological impact of increased turbidity, although well documented in the literature (e.g. Bruton, 1985), is unknown for these freshwater systems.

Due to the fairly intensive use and re-use of water resources in the U.K., many of the problems and benefits linked to IBTs are associated with water quality. Johnson (1988) has stated that IBTs can be used to dilute point-source pollution, and thus to restrict ecological damage. Rainfall events have significant effects on water quality, giving rise in agricultural catchments, to nutrient and pesticide pulses in the rivers; while acid rain can lead to the mobilisation of aluminium and other metal ions stored in the soils of the catchment. For example, the transfer of water into the recipient rivers of the Kielder Water Scheme (Hall, 1977) (Section 2.5.2; Figure 2.23), the Tees and Wear rivers, probably dilutes these effects.

Reduced flows in the Onega River, donor to the ETP (Section 2.3.1; Figure 2.16), are likely to result in a higher percentage of pollutants in the river (Voropaev and Velikanov, 1985; Micklin, 1986). Flow in another donor, the upper Sukhona River, would have been reversed below the towns of Sokol and Vologda, both sources of pulp and paper mill effluents, transferring these back to Lake Kubenskoye. This would have resulted in pollution and increased eutrophication in the lake, with a consequent threat to the lake whitefish (*Coregonus clupeaformis*). The construction of the transfer would have had to have been delayed in order to allow construction of water treatment works for the pulp and paper mill effluents. The diversion of water from the Neva River, phase IB of the ETP, would have resulted in a 5% reduction in flow and increasing pollution concentrations in the Gulf of Finland due to reduced dilution of effluents from Leningrad (Voropaev and Velikanov, 1985; Micklin, 1986).

A further water quality aspect of IBTs involves temperature change in recipient waters. One of the unpredicted impacts of the Churchill River Diversion, for example, was a decrease in water temperature in Southern Indian Lake, a receiving water body (Day, 1985) (Section 2.2.1; Figure 2.9). The proposed NAWAPA scheme (Section 2.2.1, 2.2.2) could have effects on temperatures in the recipient waterbodies, since the water in northern donor reservoirs would be several degrees colder than recipient systems in the south (Sewell, 1967; Micklin, 1977) and, in Australia, Johnson and Millner (1978) commented on the Snowy Mountains Scheme (Section 2.4.1; Figure 2.20) where water that is 6ºC cooler than the average temperatures of the Murray is released into the river. Katse Reservoir of the LHWP in southern Africa (Section 2.1.3; Figure 2.4) will be a deep, sinuous impoundment, storing just under 2 billion tonnes of water which are predicted to stratify thermally in summer. Although there is provision made for the withdrawal of water at varying depths, the temperature range of the transferred water will be smaller than that of water in the recipient Ash River (Chutter, 1993). Furthermore, temperatures in the reservoir are expected to be lower in winter and higher in summer than those of the Ash (Chutter, 1993).

Other water quality problems are associated with transfer tunnels and canals. The quality of water remaining in the transfer tunnel during times when the Kielder Water Scheme transfer (Section 2.5.2; Figure 2.23) is not operational is monitored as part of the management strategy for this scheme (Hall, 1977). This is an attempt to prevent poor quality water being flushed into the Wear each time the transfer is activated. Huntingdon and Armstrong (1974) have stated that knowledge of the time required for the flow of transferred water to get from abstraction point to user for the Ely Ouse to Essex Scheme (Section 2.5.2; Figure 2.23) is necessary for the efficient operation of the scheme. As with the Kielder Water Scheme, water quality in the transfer tunnel is monitored, since transfer of water is intermittent and water may be left to stagnate for considerable periods. The ENWC in Namibia (Section 2.1.3; Figure 2.4) is also likely to suffer from water quality deterioration in its open sections due to decomposing filamentous algae mats, for which chemical control is being considered (Petitjean and Davies, 1988a, b). Water quality in lined canals has been the object of study by several authors, in particular by Oksiyuk *et al.* (1979; 1981) on the Severskiy Donets-Donbas Canal in Russia (Section 2.3.1; Figure 2.16), where filamentous algae were identified as the main cause of water quality deterioration in the canal.

A major concern associated with IBTs is the transfer of water quality problems from donor to recipient catchments. For example, one of the anticipated areas of great concern in the proposed Chinese East Route is the transfer of water polluted by phenols, cyanides and mercury, to recipient catchments (Jinghua and Yongke, 1983). In the U.K., local fruit farmers in the Essex catchment, recipient of the Ely Ouse to Essex Scheme, developed problems with tomato fruit formation, which rendered the crop unmarketable. An analysis of water supplies revealed the presence of the pesticide 2.3.6 trichlorobenzoic acid (TBA), originating from a factory discharging to the River Cam, a tributary of the Ely Ouse (Guiver, 1976). The problem had not occurred prior to the transfer, since Ely Ouse water had never been used for crop irrigation in its own catchment (see also Huntingdon and Armstrong, 1974). It is also feared that sugar beet rhizomania will be transferred from beet factory effluents that are released into the Ely Ouse. This could lead to organic pollution in the Essex area (National Rivers Authority, 1994).

On the other hand, one of the unplanned benefits of the Ely Ouse to Essex Scheme was the control of a liquid ammonia spill in the upper reaches of the River Stour, from a sewage works unable to cope with a sudden surge of ammonia (Guiver, 1976). Water transfer from the Ely Ouse to the Stour enabled dilution of the spill to acceptable levels. Furthermore, the cost of the pumping was recovered from the sewage works responsible for the ammonia spill.

Collie and Lund (1979) reported on preliminary work on the water quality of the rivers of the Severn-Thames Transfer in the U.K. (Section 2.5.2; Figure 2.23). Algal bioassays revealed the highly fertile nature of the waters of both systems, leading to the conclusion that water transfer from the Severn to the Thames would not significantly alter either the algal or the nutrient status of the Thames, even if water was drawn only from the Clywedog Reservoir, the main upland reservoir on the Severn.

In South Africa, there have been reports of the transfer between catchments of non-toxic *geosmin*, a cyanophyte exudate. This has taken place from Theewaterskloof Reservoir, donor to the RBEGS IBT, to the receiving reaches of the Berg River (Dr W.R. Harding, Southern Waters Consulting, formerly of Cape Metropolitan Council, Directorate of Scientific Services, personal communication) (Section 2.1.3; Figure 2.4). The growth of cyanophytes, commonly of the genus *Anabaena*, in Theewaterskloof, is being encouraged by fertiliser-enriched runoff from farms within its catchment, increasing the nutrient loading of the reservoir and leading to bloom development (e.g. Harding, 1992). The presence of *geosmin* in Berg River water has affected the flesh of rainbow trout reared in a farm that takes water from the Berg a few hundred metres below the IBT outlet: the trout farmer has issued several complaints to the local authorities (W.R. Harding, personal communication). The transfer of *geosmin* points towards the possible, and more harmful, introduction of toxic cyanophyte exudates, which could have severe social and economic implications, particularly in the light of recent stock deaths directly attributable to cyanobacterial toxins in the Western Cape Province of South Africa (e.g. Harding, 1997), and toxic outbreaks in several coastal wetland systems in the Cape Peninsula.

The nature of the donor structure is of critical importance in the assessment of the effects of IBTs on water chemistry (e.g. Snaddon, 1998). The impoundment of a donor system, for example, will lead to a suite of alterations in water chemistry, as a result of the transformation of a lotic system into a lentic waterbody (e.g. Ward and Stanford, 1983). Thus, the transfer of water from a donor impoundment into a recipient river will lead to changes in the recipient that are similar to those occurring downstream of a dam (Snaddon, 1998). The RBEGS in the Western Cape Province of South Africa has, in addition to causing substantial changes in hydrology, transferred water of significantly different quality into the upper Berg River, one of the recipients of the scheme (Snaddon, 1998; Snaddon and Davies, 1998). While temperature did not show any significant correlation with the water transfer, measures of pH, conductivity, total dissolved and suspended solids, sodium, magnesium, potassium and calcium cations, and sulphate and chloride anions, were significantly higher downstream of the IBT during summer, when the transfer was in operation. All of these variables are expected to increase downstream (e.g. Harrison and Elsworth, 1958; Dallas, 1995). The IBT, however, resulted in unnaturally marked alterations in water chemistry within a short section of river (< 1000 m), and it has been suggested that these alterations are due to the impoundment of the water before transfer.

3.4 Biological Effects

3.4.1 Invertebrates

The loss and modification of instream invertebrate habitat will inevitably occur in donor systems with changes in flow, sediment transport and channel morphology. For example, aquatic insects colonising the gravel substratum of the Snowy River are likely to be influenced by the accumulation of fine tributary sediments on the river bed. Studies by Doeg *et al.* (1987) in gravel-bed streams of south-east Australia, have indicated that increased levels of fine sediment, due to catchment modification, have reduced the abundance of the aquatic insect orders Trichoptera, Diptera, Plecoptera and Ephemeroptera. Increased levels of fine sediment fill the interstitial pores between the gravel clasts, reducing habitat space, as well as the dissolved oxygen content of interstitial water.

In the United States, Golladay and Hax (1995) investigated the effects of a transfer of water from Lake Texoma on the Oklahoma-Texas border (Red River basin), through a 16-km pipeline, to the headwaters of Sister Grove Creek and eventually into Lake Lavon in Texas (Trinity River basin) (see also Schorr *et al*., 1993) (Section 2.2.2; Figure 2.12), on the invertebrates of the recipient river. The transferred water flows along 50 km of Sister Grove Creek before reaching Lake Lavon. Sister Grove Creek is usually an intermittent stream, with seasonal extremes in flow (Matthews *et al.*, 1996). Golladay and Hax (1995) investigated the effects of experimentally increased flows on the meiofauna of Sister Grove Creek. Meiofauna (45-500 µm) are particularly susceptible to higher discharges: they are poor swimmers and are prone to drift, rather than able to resist flow. The meiofauna of Sister Grove Creek was sampled from two different habitat types, namely sediment and small woody debris (<3 mm diameter), at two disturbed sites and one undisturbed site, before and after a 2-week water diversion from Lake Texoma. Before diversion, meiofaunal populations in Sister Grove Creek were stable or increasing in numbers in both habitat types at all sites. Nematodes, copepods and rotifers accounted for 85-99% of the meiofauna in the sediment; while chironomids, nematodes and rotifers accounted for 80-92% of the meiofauna on the woody debris. After the diversion, meiofaunal densities in the sediment habitat type were reduced to 1-2% of pre-diversion levels, and all taxa were affected, while on the woody debris, meiofaunal densities decreased to 10-17% of pre-diversion levels. The wood meiofauna were thus more resistant to flow increases than those in the sediments. Furthermore, one month after diversion, greater recovery was observed on the woody debris than in the sediments. The authors concluded that woody debris probably provides important refuges during floods, and recolonisation sources after floods.

In Norway, Brittain *et al.* (1984) investigated the effects of a diversion of 80% of the flow of the Glåma to the Rena River (Section 2.5.1; Figure 2.22) on the benthic macroinvertebrates of the Glåma, while Borgstrøm and Løkensgard (1984) undertook a similar study on the fish fauna. The purpose of the transfer is to provide water for hydro-electric power generation in the Rena catchment. Only the donor river was sampled, and thus the results of the study are not unique to water transfer, but rather are as a result of water abstraction. The effects on the benthic invertebrates were greatest during winter, when the percentage reduction in water flow was greatest. Brittain *et al.* (1984) found that densities of Trichoptera, Ephemeroptera and Plecoptera were considerably lower below the transfer site. The benthic species which grew most during winter were most affected by the diversion. For example, the winter-growing Capniidae Plecoptera were eliminated below the transfer, while the winter generations of the baetid Ephemeroptera, *Baetis rhodani*, were severely reduced. In addition, species that are characteristic of the slower-flowing sections of the Glåma tended to colonise the river below the diversion. Densities of filter-feeding trichopterans, for example of the genus *Hydropsyche*, increased below the transfer site, while a species of plecopteran, *Diura nanseni*, increased in dominance. Recovery was fairly rapid below the transfer site during summer, with benthic densities by August resembling those at the undisturbed sites above the diversion. Spring spates played an important role in recolonisation of depauperate sections of the river below the transfer, especially from tributaries that were unaffected by the transfer. Working on the same system, Brittain and Bildeng (1995) found that the life-cycles of a species of Trichoptera, *Arctopsyche ladogensis*, occurring in the regulated reaches of the Glåma, were fairly flexible. Individuals of this species had both one- and two-year life-cycles, which they suggested was advantageous in regulated rivers, where temperatures and flows fluctuate beyond natural levels. Such flexibility is not common amongst riverine invertebrates.

Table 3.6 A summary of the effects of IBTs on aquatic invertebrates, as reported in the text.

Country	Scheme	Effects (actual and potential)
Invertebrates		
Australia	Snowy Mountains Scheme	• aquatic insects likely to be affected by the accumulation of fine sediments on the Snowy River bed
Norway	Glåma-Rena Transfer	• densities of Trichoptera, Ephemeroptera and Plecoptera considerably lower below donor impoundment
South Africa	Orange River Project	• significant changes in riverine invertebrate species composition in recipient Great Fish River, with only 33% of taxa common to pre-and post-transfer communities • significant shifts in the dominant dipteran Chironomidae and Simuliidae species, and trichopteran Hydropsychidae • pest species of simuliid, *Simulium chutteri*, outcompeted other species, and causes stock damage and losses • increase in high flow velocity habitats favoured establishment of simuliid larvae
South Africa	RBEGS	• invertebrate communities below IBT had significantly greater numbers of individuals, and lower overall richness and numbers of taxa • overall loss of sensitive invertebrate taxa • filter-feeding taxa appeared to benefit from the water transfer • transfer of lentic taxa from donor impoundment
Southern Africa	LHWP	• invertebrate communities in recipient Ash/Liebenbergsvlei system expected to be affected by loss of habitat and smothering by filamentous algae that will establish in the sediment-free water transferred from Katse • transfer of lentic taxa to recipient is expected • filter-feeding taxa expected to benefit in recipient system • establishment of pest simuliids in recipient system is possible
U.K.	Ely Ouse to Essex Scheme	• screening and chlorination of Ely Ouse water are necessary to prevent the spread of the alien zebra mussel, *Dreissena polymorpha*, and diatom blooms
U.K.	Kielder Water Scheme	• live mayfly and chironomid taxa transferred to the River Wear, as well as dead and fragmented cladocerans
U.S.A.	Lake Texoma-Lake Lavon Transfer	• substantial reductions in meiofaunal populations on fine sediment and woody substrata

One of the few studies of the ecological effects of IBTs in South Africa was undertaken by O'Keeffe and De Moor (1988). A comparison of the pre- and post-transfer benthic macro-invertebrate communities of the Great Fish River, one of the recipients of the ORP (Section 2.1.3; Figure 2.4), was developed using data collected by researchers in the 1970s (e.g. Scott *et al.*, 1972). O'Keeffe and De Moor (1988) reported that the species richness of the benthic invertebrate fauna of riffles had changed little as a result of flow increases in the river. The numbers of taxa increased from 41 taxa before to 47 taxa after the transfer. The species composition, however, had changed considerably, with only 33% of taxa common both to pre- and to post-transfer samples. In particular, they recorded significant shifts in the dominant dipteran Chironomidae and Simuliidae species, and trichopteran Hydropsychidae. Most pronounced was the shift to dominance by the pest blackfly species *Simulium chutteri*, to the detriment of the original benign populations of *Simulium adersi* and *S. nigritarse*, which were previously co-dominant. *Simulium chutteri* now causes severe damage to livestock in the lower reaches of the river: the feeding activities of swarms of adult females cause stock damage and disturbance during spring (see also Scott *et al.*, 1972; O'Keeffe, 1982, 1985). All of these shifts in the invertebrate fauna can directly be attributed to the changes in flow regime caused by the transfer, particularly the loss of flow variability, and the shift from a seasonal to a perennial river. This has led to an increase in the total area of available erosional habitats, which are favoured, in particular, by simuliid larvae.

Another ecological study on the effects of an IBT on benthic invertebrates was performed on the RBEGS in the Western Cape Province of South Africa (Snaddon, 1998; Snaddon and Davies, 1998, 2000) (Section 2.1.3; Figure 2.4). During summer in the Berg River, when the IBT was releasing water into the river, the invertebrate communities below the IBT were markedly different to those collected above it. The below-IBT communities were typical of outlet communities occurring below impoundments. These communities had significantly greater numbers of individuals, and lower overall richness and numbers of taxa. Furthermore, an overall loss of sensitive invertebrate taxa was recorded below the IBT, while a number of tolerant filter-feeding taxa appeared to benefit from the water transfer. The Hydropsychidae (Trichoptera) were recorded in particularly high numbers downstream of the IBT during summer. The success of this group was probably due to the transfer through the tunnel of zooplanktonic groups from Theewaterskloof. These included the crustacean orders, Cladocera and Copepoda. During winter, when water transfer ceased, the Berg River invertebrate communities below the IBT recovered to resemble the unimpacted communities recorded above the IBT. This temporal recovery reached its maximum towards the end of the winter, before the IBT tunnel discharged the first summer release (Snaddon, 1998; Snaddon and Davies, 2000).

Similar transfers of invertebrate taxa were recorded in the receiving reaches of the River Wear in the U.K. (Gibbins, 1996). The River Wear receives water from the Kielder Water Scheme. Live mayfly and chironomid taxa were found in transferred water, while dead and fragmented clodocerans (of the species *Daphnia longispina*) were also recorded. The implications of these transfers of biota have not been assessed in the U.K., but they could have important long-term effects on the biota of the River Wear.

The benthic macroinvertebrate communities downstream of Katse Dam of the LHWP (southern Africa) are also predicted to be affected by physical alterations in habitat - such as smothering by benthic algae, and loss of riffle biotope for the establishment of early instars - by changes in water quality and, by a reduction of inputs of coarse organic matter from riparian vegetation (Chutter, 1993). In addition, lentic faunal groups, such as zooplankton developing in the reservoir, can be expected to be released from Katse Dam, thereby providing a ready and greatly altered food source for the downstream biota (e.g. Snaddon , 1998; Snaddon and Davies, 1998). Some invertebrate taxa will benefit from these conditions, such as filter-feeding hydropsychid caddisfly larvae and simuliid larvae, while others will not be able to tolerate the new environmental conditions. The major pest species of Simuliidae of the Orange River, *Simulium chutteri*, has been recorded in low numbers in both the Malibamatso and Liebenbergsvlei rivers, and of concern is the fact that a rapid increase in numbers of this species to economically serious proportions has already been well-documented for river reaches below dams further down the Orange/Vaal River system, so much so, that major eradication campaigns are in progress using biological control methods (e.g. Car and De Moor, 1984; De Moor, 1982; De Moor *et al*., 1986). Similar increases in numbers could well occur in the Malibamatso, Nqoe and Ash rivers, where manipulation of flow conditions coupled with temperature changes and alterations in type and quantity of food material could encourage the establishment of this species.

Lastly, in Britain, screening and chlorination of transfer water in the Ely Ouse to Essex Scheme is primarily done in order to prevent the growth of the invasive zebra mussel, *Dreissena polymorpha*, and to reduce diatom blooms. It appears that this has been effective (Boon, 1988).

3.4.2 Fish

In many cases, water transfers result in the alteration of habitat necessary for the survival or establishment of fish fauna. Matthews *et al*. (1996) conducted a study on the Lake Texoma-Lake Lavon transfer which is described above (Sections 2.2.2. and 3.4.1). They investigated the effects of experimentally increased flows on the fish fauna of the recipient stream, Sister Grove Creek. The releases were made into Sister Grove Creek during periods of lowest flow, resulting in marked increases in flow and conductivity. Three trial flows were released, each lasting for 2 weeks or less. Matthews *et al*. (1996) collected data before, during and after the experimental releases. Analyses of data showed moderate changes in the fish fauna of Sister Grove Creek after the trial flows. Small changes in abundance of individual fish species were recorded, while, at some sampling stations, quantitative and qualitative changes in species composition of the fish assemblage were substantial.

Table 3.7 A list of the effects of IBTs on fish.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Fish			
Canada	Liard-Stikine Diversion **PROPOSAL**	• was expected to introduce trout to the upper Liard River, and also to transfer northern pike, *Esox lucius*, along with its tape-worm, *Triaenophorus crassus*, from the Stikine to the Liard River.	
Canada	Long Lake and Ogoki Diversions	• transfer of sea lamprey was avoided due to the presence of natural barriers and hydro-electric power dams	
Canada	Long Lake and Ogoki Diversions	• increased fish-egg mortality in recipient systems, due to increased erosion	
Canada	Kemano Diversion	• Nechako chinook salmon were adversely affected by flow disruptions from the closure of dams, warm-water releases and siltation in the donor Nechako River • increased discharges in the recipient Kemano River have resulted in pink and chum salmon runs	court injunction
Lesotho	LHWP	• Katse Dam is expected to be a barrier to upstream spawning runs of some fish species in the Malibamatso River	
Namibia	ENWC	• fish transfers from the Okavango River to the recipient Omatako and Swakop rivers, are expected, including *Oreochromis andersonii* (three spot bream), *Clarias gariepinus* (sharp-toothed catfish), and *Tilapia sparmanii* (banded bream)	
North America	Garrison Diversion Project **PROPOSAL**	• Missouri River species are expected to establish in new habitat made available in Canada by the IBT, including the shovelnose sturgeon *Scaphirhynchus platorynchus*, paddlefish *Polyodon spathula*, shortnose gar *Lepisosteus platostomus*, gizzard shad *Dorosoma cepedianum*, rainbow smelt *Osmerus mordax*, river carpsucker *Carpiodes carpio*, smallmouth buffalo *Ictiobus bubalus*, Utah chub *Gila atraria*, and the endangered pallid sturgeon *Scaphirhynchus albus* • existing populations of walleye *Stizostedion vitreum*, sauger *S. canadense*, lake whitefish *Coregonus clupeaformis* in lakes Manitoba and Winnipeg are expected to decline as a result	
Norway	Veo-Smådøla Transfer	• reduced recruitment and availability of important food organisms has resulted in reduced numbers of introduced brown trout, *Salmo trutta*, in the recipient Smådøla River	
Norway	Lake Suldalsvatnet to Hylsfjorden Transfer	• the possibility exists that returning salmon will enter Hylsfjorden rather than Suldalslågen, as a result of the transfer of population-specific pheromones to Hylsfjorden	IBT ceases during salmon run seasons
South Africa	ORP	• transfer of four species to the recipient Great Fish River as a result of the IBT: smallmouth yellowfish, *Barbus aeneus*, the Orange River mudfish *Labeo capensis*, the sharptooth catfish, *Clarias gariepinus* and the rock barbel, *Gephyroglanis sclateri* • also likely that new individuals have been added to recorded populations in the Great Fish	
Spain	Tajo-Segura Transfer	• the gudgeon, *Gobio gobio*, has been introduced into the Segura River from the donor Tajo River	

Table 3.7 continued…

U.K.	Severn-Tame Transfer	• establishment of new populations as a result of increased baseflows in the recipient Tame River • reduced numbers in the River Severn, as a result of barriers to migration	
U.K.	Kielder Water Scheme	• flow changes are expected to lead to shifts in spawning grounds	
U.K.	Ely Ouse to Essex Transfer Scheme	• transfer of the predatory fish, *Stizostedion lucioperca*, appears to have occurred, from Ely Ouse to the recipient River Stour	
U.S.A.	Lake Texoma-Lake Lavon Transfer	• changes in abundance of individual fish species were recorded in the recipient Sister Grove Creek • quantitative and qualitative changes in species composition of the fish assemblage were substantial at some sites in the recipient • abundance of two minnows increased, and the abundance of one centrarchid species decreased, in Sister Grove Creek	
U.S.A.	Kansas Plains irrigation transfers	• absence of flood peaks in Kansas plains systems has eliminated turbid-water species reliant on floods for spawning • shifts to narrower, clearer streams with firmer substrata have resulted in different fish assemblages, with planktivores and piscivores more dominant • increase in planktonic groups due to absence of flushing flows	
U.S.A.	California State Water Project	• decreased numbers of the introduced striped bass, *Morone saxatilis*, the threatened delta smelt, *Hypomesus transpacificus*, and the endangered winter run chinook salmon, *Onchorynchus tshawytscha* • spring-run chinook salmon have also declined significantly, perhaps due to IBT-related flow fluctuations	
U.S.A.	Los Angeles Aqueduct	• Owens sucker, *Catostomus fumeiventris*, was transferred to the Los Angeles Basin from northern donor rivers	

Diversion of water from Lake Texoma resulted in increased discharges that were well above the average natural flows for the season, leading to a doubling of the conductivity of Sister Grove Creek (the salts that increased were largely sodium and chloride). The increased flows were sustained for periods that exceeded the natural period of high flow after a storm and, in addition, these artificial flows were not accompanied by other events associated with storms, such as increased allochthonous input, meteorological changes, and increased surface runoff. All of these events are significant in terms of fish distribution and behaviour.

Analysis of the data showed an overall decrease in variation in the fish fauna after water transfers began, while no lake species were introduced into Sister Grove Creek upstream from Lake Lavon, or from the Red River basin. Most species showed non-significant changes in abundance after the transfer, with a few exceptions: the abundance of two minnows increased significantly, while the abundance of one centrarchid species in Sister Grove Creek decreased after the transfer. The species showing increases in abundance were those adapted to harsh physical conditions.

The authors suggested that conclusive results realistically can only be gained after the transfer has been in operation for a longer period. For example, prolonged high discharges may have different effects on the river, such as modified habitat due to erosion of the channel and stream banks and the removal of woody debris. The fish of the Sister Grove Creek system are adapted to seasonal flooding. During floods, juveniles and adults find hydraulic refugia in low-flow areas, where they remain until water levels decrease. Larval fish, however, are washed out of stream segments. The authors state that probably the most important condition for the success of the fish species is the availability of suitable habitat. If the prolonged increases in flow due to the transfer lead to increased scouring of the channel, input of mud and silt, and the export of debris and its associated biota, fish that rely on these habitats may decrease.

Remaining in the USA, Cross and Moss (1987) reported that aquatic habitats and fish assemblages of plains streams in Kansas changed because of a variety of factors, including water transfers for irrigation. In the Kansas plains, the fish fauna have adapted to shallow streams subject to fluctuating flows and shifting sand beds. Transfers have eliminated extreme annual variation in discharge, thereby causing channels to narrow, become more uniform in depth, and firmer in substratum. The absence of flood peaks has elevated plankton populations and reduced, or eliminated, predominant turbid-river fishes dependent on floods to trigger spawning, while the increased water clarity has favoured a different fish species assemblage, including sight-feeding planktivores and piscivores.

Further west, the California State Water Project (CSWP) (Section 2.2.2; Figure 2.12) was designed to pump water from a forebay in the southern Sacramento-San Joaquin Delta to the San Joaquin Valley and southern California through the California Aqueduct. Flow changes, as a result of pumping, have been implicated as contributing factors in the decline of the introduced striped bass, *Morone saxatilis*, the threatened delta smelt, *Hypomesus transpacificus*, and the endangered winter-run chinook salmon, *Onchorynchus tshawytscha*. Rather than following the lesser flows of traditional spawning areas, adult striped bass have followed the enhanced diverted flows of water transfer leading the fish to unsuitable spawning areas (Stevens *et al*., 1985). Chinook salmon also use the Delta for migration and as nursery habitat, and spring and fall runs support extensive sport and commercial fisheries. Populations of spring-run chinook salmon have declined significantly, perhaps due to flow fluctuations as a result of water transfer from the Delta (Campbell and Moyle, 1990).

In Norway, Borgstrøm and Løkensgard (1984) investigated the effects of a diversion of flow from the Glåma to the Rena River on the fish fauna of the Glåma (Section 2.5.1; Figure 2.22). The authors reported a reduction in grayling (*Thymallus thymallus*) recruitment and numbers, while brown trout (*Salmo trutta*) appeared unaffected by the reductions in flow and wetted area that resulted from the transfer. They attributed these observations to the reduction in the density and diversity of benthic invertebrates below the transfer, as recorded by Brittain *et al.* (1984; see Section 3.4.1), which are the favoured prey of grayling; trout feed on small fish. In addition, grayling appeared to be more dependent on flow and the availability of habitat, especially as refuges for immature individuals. Reduced recruitment of grayling has also led to increased fishing pressure on this species. Also in Norway, Hesthagen and Fjellheim (1987) studied the effects of glacier-fed water transferred from the River Veo on the production and food source of brown trout in the receiving Smådøla River (Section 2.5.1; Figure 2.22). Although not an indigenous fish in the Smådøla, transfers of water to the river significantly reduced production of this fish from 271.5 to 103.1 g 100 m^{-2} yr^{-1}. This was due primarily to reduced recruitment and availability of important food organisms.

As a result of the Long Lake and Ogoki Diversions in Canada (Section 2.2.1; Figure 2.9), changes in the magnitude of artificially high or low water levels have resulted in erosion in the recipient systems and, thus, in increased fish-egg mortality (Day, 1985). In the U.K., Mann (1988) noted that treated Wye and Severn water which had been used by the Birmingham Industrial Complex and which was released to the River Tame (a tributary of the Trent River), had enabled the establishment of fish populations in the river as a result of increased baseflow. However, reduction in flow as a result of abstraction from the River Severn has resulted in the creation of barriers to migratory fish. Hancock (1977) has dealt theoretically with the effects on fish populations (in particular grayling and trout), of the Kielder Water Scheme in the U.K., and predicted that flow changes would lead to a shift of spawning grounds.

The effects of flow alterations on fish stocks were learnt the hard way in Canada, where the likely environmental consequences of the Kemano Diversion were not evaluated before construction, and which led to the decimation of Nechako chinook salmon stocks (Day, 1985). In an attempt to encourage industrialisation in its mid-coastal region, the provincial government of British Columbia provided substantial financial incentives to the Canadian Aluminium Company, Alcan, to develop a hydroelectric power plant and smelter at Kemano. The result was the storage and diversion of up to 269 m^3 s^{-1} (8 x 10^9 m^3 yr^{-1}) of water from the Nechako and Nanika rivers and Skins Lake, into the Kemano River. The Nechako chinook salmon were adversely affected by flow disruptions from the closure of dams, warm-water releases and siltation (Day, 1985). Subsequently, flows to the Nechako River had to be ensured by a British Columbia Supreme Court injunction, in order to protect sockeye salmon (*Oncorhynchus nerka*) migration routes. Increased discharges in the Kemano River have, however, resulted in pink (*Oncorhynchus gorbuscha*) and chum salmon (*Oncorhynchus keta*) runs in this river. In 1980, Alcan refused to allow the renewal of the court injunction permitting the Minister of Fisheries and Oceans to set flows on the Nechako River that are necessary to maintain fish populations. This coincided with plans to further develop the Kemano Diversion, and resulted in a trial in August 1987. An out-of-court settlement was reached in September 1987, whereby Alcan renounced all rights to the Nanika River and the nearby Murray-Cheslatta system in return for a variety of benefits, among them the freedom from the responsibility to provide more water to the Nechako should compensation flows prove inadequate to support the salmon and sports fisheries, and the assurance that no further mitigation and compensation would be demanded from Alcan. In addition, compensation and cold-water flows that were set in the final agreement were substantially lower than those previously determined by the Minister. Most significant in the settlement, a review of which is provided by the Rivers Defence Coalition (1988), is that the Minister of Fisheries lost the right to regulate flows on the Nechako for fish protection. Additional effects of the final agreement, such as reduced irrigation water available from the Nechako River, and damage to the aesthetics and recreational potential of the area, were ignored in the final, out-of-court settlement.

In southern Africa, there are a few indigenous fish species in the Malibamatso River, donor to the LHWP (Section 2.1.3; Figure 2.4), that make upstream spawning runs: these runs will be obstructed by Katse Dam, thereby reducing habitat availability to these fish species, restricting spawning to downstream reaches of the river (Chutter, 1993).

Apart from fish habitat changes brought about by IBTs, the actual transfer of species has been recorded in a number of cases. For instance, it appears that a minimum of four species are likely to have been introduced to the Great Fish River from the Orange River *via* the Orange/Fish tunnel of the ORP (e.g. Cambray and Jubb, 1977; Laurenson and Hocutt, 1984, 1986) (Section 2.1.3; Figure 2.4). These include the smallmouth yellowfish, *Barbus aeneus*, the Orange River mudfish *Labeo capensis*, the sharptooth catfish, *Clarias gariepinus* and the rock barbel, *Gephyroglanis sclateri*. Transfer of these species may threaten the endangered natural and endemic populations in the Great Fish. Furthermore, it is likely that individuals of species already present in the recipient system have also been transferred from the Orange River, thereby mixing previously isolated gene pools of the same species in the Great Fish River (Jubb, 1976; Cambray and Jubb, 1977; Cambray and Hahndiek, 1979; Laurenson and Hocutt, 1984, 1986; Bruton and Van As, 1986).

The transfer of the predatory zander (*Stizostedion lucioperca*) appears to have occurred from the Ely Ouse system to the Stour, one of the recipients of the Ely Ouse to Essex Transfer (National Rivers Authority, 1994) (Section 2.5.2; Figure 23). It was originally thought that the pumps and high water pressures associated with the transfer system would prevent the transfer of live fish. Live fry have, however, successfully completed the journey, with as yet unassessed impacts on the indigenous fish fauna. Although electric screens have been considered in order to prevent the further transfer of fish, no action has as yet been taken. Since it is probable that both fry and eggs are transferred, the installation of electric screens will most likely be of minimal efficiency (Guiver, 1976). In this context, it is important to note that, although no IBT was involved, the Lake Tanganyika sardine, *Limnothrissa miodon*, has successfully passed through turbines and 200 km of river to pass from lakes Kariba to Cahora Bassa, on the Zambezi River in southern Africa (e.g. Davies and Day, 1998).

García De Jalón (1987) reported that one of the ecological impacts of the Tajo-Segura transfer, Spain (Section 2.5.4; Figure 2.25), has been the introduction, and colonisation of the Segura by the gudgeon (*Gobio gobio*). However, the effects of the introduction of the gudgeon on the indigenous fish populations of the Segura, and other rivers in Spain, is at present unknown. These populations are adapted to high temperatures and low summer flows, and river regulation in the Segura has resulted in a complete reversal of flow and temperature regime (i.e. cooler summer maximum flows). In Namibia, transfers of water from the Kavango River to the Omatako Dam and Swakop River *via* the ENWC (Section 2.1.3; Figure 2.4) are proposed to occur when the need arises. These transfers will probably facilitate the introduction of three spot bream (*Oreochromis andersonii*), sharp-toothed catfish (*Clarias gariepinus*), and banded bream (*Tilapia sparmanii*) to the recipient systems, which could lead to direct intraspecific competition with existing populations of the same species (Skelton and Merron, 1984).

Hubbs *et al*. (1943) reported on the transfer of the Owens sucker (*Catostomus fumeiventris*) to the Los Angeles Basin *via* the Los Angeles Aqueduct (Section 2.2.2; Figure 2.12). This is the oldest IBT in California, which was completed in 1913 in order to transfer water from Owens Valley on the eastern slopes of the Sierra Nevada Mountains to the city of Los Angeles. Further north, Lindsey (1957) reviewed the distribution of freshwater fish in drainages of the British Columbia mainland, with reference to proposed water diversions for hydro-electric power development. A proposed Liard-Stikine diversion, which would link the Arctic and Pacific drainages, would almost certainly introduce trout to the upper Liard River, and would probably transfer northern pike (*Esox lucius*), along with its tape-worm (*Triaenophorus crassus*), from the Stikine to the Liard River. The introduction of the tapeworm to the Liard River would have a significant impact on the economic value of Pacific salmon in this river. With respect to the Long Lake and Ogoki Diversions in Canada (Section 2.2.1; Figure 2.9), the transfer of sea lamprey from Lake Superior to the Albany River system (into which both the Ogoki and Long Lake systems drain) was fortunately avoided by the presence of hydro-electric power dams, which, along with some natural barriers, have prevented the spread of these aliens (Day *et al.*, 1982; Day, 1985).

The international Garrison Diversion Project (Section 2.2.2) provides a compelling case for the potential of introduced biota. At least nine fish species native to the Missouri River, but not to Canada, could be expected to invade new environments made available by the Garrison Diversion Project (Oetting, 1977). They are the shovelnose sturgeon (*Scaphirhynchus platorynchus*), paddlefish (*Polyodon spathula*), shortnose gar (*Lepisosteus platostomus*), gizzard shad (*Dorosoma cepedianum*), rainbow smelt (*Osmerus mordax*), river carpsucker (*Carpiodes carpio*), smallmouth buffalo (*Ictiobus bubalus*), Utah chub (*Gila atraria*), and the endangered pallid sturgeon (*Scaphirhynchus albus*). Populations of three species in particular, the Utah chub, gizzard shad, and rainbow smelt, could be expected to increase in Lakes Manitoba and Winnipeg, to the detriment of walleye (*Stizostedion vitreum*), sauger (*S. canadense*), lake whitefish (*Coregonus clupeaformis*), and other commercial and sport fish species. Walleye, sauger, and whitefish populations may disappear when exotic populations become established, possibly bringing about the total collapse of the commercial fisheries in the two lakes (Keys, 1984). Biologists proposed the addition of a fish screen and a sand filtration system to inhibit transfer of biota. However, the Canadian government has not been convinced that these additions provide a sufficient guarantee against the introduction of non-native biota. The issue of introduced biota remains unresolved, and the future of the Garrison Diversion Project remains unclear.

A further interesting and possibly severe effect of IBTs relates to the release of population-specific pheromones by juvenile, anadromous salmonids and their homeward migration as adults. The hypothesis, which was put forward by Nordeng (1977) as a result of work on the Salangen River in Norway, suggests that homeward navigation by these commercially important fish species is an inherited response to population-specific pheromone trails released by descending smolt. The juvenile fish release the pheromones from their skin mucus as they move downstream during their migration to the sea during spring and summer. The hypothesis has serious implications for IBTs where the rivers involved support anadromous fish species that use this adaptation for home recognition. Water transferred between basins would have the consequence of leading homebound adults into an incorrect river for spawning due to deceptive pheromone trails, which would ultimately result in the depletion of fish stocks. It was on the strength of this hypothesis that Tøndevold (1984) recommended that transfers of water from Lake Suldalsvatnet to Hylsfjorden, also in Norway (Section 2.5.1; Figure 2.22), cease during June and July during salmon runs, in order to reduce the possibility of returning salmon entering Hylsfjorden rather than Suldalslågen. This recommendation was, in fact, carried out.

3.4.3 Fish Parasites

The McGregor Diversion (Section 2.2.1; Figure 2.9) was shelved in 1978 as a result of the possible transfer of both fish and parasites from the Fraser River to the Arctic-draining Peace River (Day, 1985). Arai and Mudry (1983), in a study of possible protozoan and metazoan fish parasite transfers from the headwaters of the McGregor River (Pacific drainage) in British Columbia, to the Parsnip River (Arctic drainage), showed that 26 parasites had disjunct distributions in the study area. Three forms were identified as posing a significant threat to the fisheries resources of the immediate area and also to downstream areas. Based in part on these studies, the British Columbia Hydro and Power Authority suspended engineering studies of the proposed diversion.

Arthur *et al.* (1976) undertook a similar study of the potential consequences of the transfer of fish parasites from Stevens Lake to Aishihik Lake (Yukon Territory, Canada) as a result of an interlake diversion for hydro-electric power generation, the Stevens-Aishihik Inter-Lake Transfer. Several species of parasite, of potential economic and pathogenic importance, were identified as likely candidates for transfer. Amongst these were *Henneguya zschokkei* and *Hexamita salmonis* (Protozoa), *Discocotyle sagittata* (Monogenea) and *Triaenophorus nodulosis* (Cestoda). These species are parasites of the lake whitefish (*Coregonus clupeaformis*), round whitefish (*Prosopium cylindraceum*), burbot (*Lota lota*), lake trout (*Salvelinus namaycush*), Arctic grayling (*Thymallus* *arcticus*) and the northern Pike (*Esox lucius*). *Triaenophorus nodulosis* was found only in Stevens Lake, while the other three species occurred in Aishihik Lake.

Table 3.8 The effects of IBTs on fish parasites, as reported in the text.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Fish Parasites			
Canada	McGregor Diversion	• Transfer of fish and their protozoan and metazoan parasites was expected between the Pacific-draining donor Fraser River and the Arctic-draining recipient Peace River	IBT proposal was shelved
Canada	Stevens-Aishihik Inter-Lake Transfer	• several species of parasite, of potential economic and pathogenic importance, were identified as likely candidates for transfer	

3.4.4 Human Diseases and Disease Vectors

An important consequence of water transfers is the transfer of diseases and disease vectors between catchments, or the creation of habitat which is suitable for the establishment of pests which pose threats to human and animal health. For example, an environmental problem associated with a proposed Texas Water Plan (USA) was the transfer of water to certain areas of West Texas, where the encephalitis-carrying mosquito is found (Greer, 1983). The delivery of large quantities of water could have led to their proliferation. The Texas Water Plan was designed to transfer water from the Mississippi River, and rivers in the eastern half of Texas, to rivers and reservoirs in the west and south-west of the state. These plans have been shelved, due to the discovery that abstraction of water from the Mississippi at the intended scale, was not economically feasible (Greer, 1983).

In Russia, the potential exists for the transfer of water-borne diseases and parasites along the 2000 km unlined transfer canal from Tobol'sk in Western Siberia to the Amudar'ya in Central Asia, which was the proposed transfer route for SCAP (Gorodetskaya, 1982) (Section 2.3.1; Figure 2.16). Still in Russia, an aspect of the ETP investigated by Voronov *et al.* (1983), is the possible effect that the transfer would have on the aggravation, or attenuation, of a variety of epidemiological conditions within the recipient area. The main effect was likely to have been the spread of opisthorchiasis (liver-fluke disease) and diphyllobothriasis (Broad Fish tapeworm) along the entire length of the proposed canal (see also Kuperman, 1978). This would be due to the possible transfer of the respective intermediate hosts *Bithynia leachii* (a freshwater snail) and *Cyclops* sp. (a crustacean) to the southern regions where, at present, these invertebrates are almost absent. The increased supply of water to the midland regions was also likely to encourage the establishment of water fever in these areas.

The ENWC, in Namibia (Section 2.1.3; Figure 2.4), could transfer schistosomiasis (bilharzia) from the Kavango River to recipient areas. Control of the host snails is being studied, but it is possible that the three dams in the scheme could become reservoirs of infection (Department of Water Affairs and the Department of Agriculture and Nature Conservation, South West Africa/Namibia, 1987).

The only ecological investigations that accompanied the construction of the Tugela-Vaal Scheme in South Africa (Section 2.1.3; Figure 2.4), were related to the potential transfer of the schistosomiasis host snails *Biomphalaria* sp. (intestinal bilharzia) and *Bulinus* (*Physopsis*) sp. (urinary bilharzia) from the donor Tugela River to the recipient Vaal system: the disease does not occur in the Vaal catchment (Pitchford and Visser, 1975; Pretorius *et al.*, 1976). The problem was of concern due to the fact that Pitchford (1953) had shown that snail ova are hardy and could pass through the mechanical components used in IBTs. However, there has fortunately been no evidence of the establishment of snail populations in the Vaal due possibly to prevailing winter temperatures in the system (Professor J. De Kock, Snail Research Unit, Potchefstroom University, personal communication, 1996). The Tugela-Vaal Scheme was one of the first designed in South Africa, involving the pumping of water from the Tugela, in KwaZulu-Natal province in the east of the country, over the intervening mountain range to the interior, in order to augment water supply in the Vaal River catchment (Department of Water Affairs and Forestry, 1991b).

Table 3.9 A summary of the human diseases and disease vectors associated with IBTs.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Human Diseases and Disease Vectors			
Egypt	Jonglei Canal	• probable that snails, found to be intermediate hosts to trematode parasites causing several diseases in humans and stock, could colonise the margins of the main Jonglei Canal, and secondary, draw-off canals, and could populate the new wetland habitat created by the IBT	
Namibia	ENWC	• the transfer of schistosomiasis (bilharzia) from the Kavango River to recipient areas is expected	
Russia	SCAP **PROPOSAL**	• potential transfer of water-borne diseases and parasites along open canals	
Russia	ETP **PROPOSAL**	• the transfer of the intermediate parasite hosts *Bithynia leachii* (a freshwater snail) and *Cyclops* sp. (a crustacean) to southern regions was expected where, at present, these invertebrates are almost absent; these invertebrates are the carriers of opisthorchiasis (liver-fluke disease) and diphyllobothriasis (Broad Fish tapeworm) • the increased supply of water to the midland regions was also likely to encourage the establishment of water fever in recipient areas	
South Africa	Tugela-Vaal Transfer	• it was expected that the freshwater snail hosts for schistosomiasis, *Biomphalaria* sp. (intestinal bilharzia) and *Bulinus* (*Physopsis*) sp. (urinary bilharzia), would be transferred from the Tugela to the Vaal system	this has not occurred, due to temperature differences between the two rivers
U.S.A.	Texas Water Plan **PROPOSAL**	• the release of large quantities of water could have led to the proliferation of the encephalitis-carrying mosquito	

The spread of aquatic snails was also one of the major concerns about the Jonglei Canal in Egypt (Section 2.1.1; Figure 2.1). Brown *et al*. (1984) undertook a two-year assessment of the occurrence of freshwater snails and their parasites in the area affected by the Canal. They recorded 23 species of snail in the region, of which several are intermediate hosts to trematode parasites, which can infect humans, livestock and wild herbivores. These parasites cause diseases such as schistosomiasis, fascioliasis and amphistomiasis (caused by stomach or conical flukes). Brown *et al*. (1984) suggested that it is likely that snails would colonise the margins of the main Jonglei Canal, and secondary, draw-off canals, probably in greater numbers than pre-Canal populations. In addition, the Jonglei Canal interrupts the east-west drainage across the floodplain between the offtake and release points; this will lead to an increase in permanent and semi-permanent wetlands on the eastern side of the canal. Aquatic snails would benefit from this available habitat. The floating macrophytes, *Pistia stratiotes* (water cabbage) and *Eichhornia crassipes* (water hyacinth), were also thought to be likely means of transportation of the snails.

3.4.5 Vertebrates Other Than Fish

It is believed that the migration routes of great herds of Caribou would be blocked by the physical barriers that the canals and reservoirs of NAWAPA (Sections 2.2.1, 2.2.2) would have created, and this would also have affected those human communities reliant on the Caribou as a source of food (Nace, 1966).

Table 3.10 The effects of IBTs on vertebrates, other than fish.

Country	Scheme	Effects (actual and potential)
Vertebrates other than Fish		
Namibia	ENWC	• open canal is a trap for animals
North America	NAWAPA **PROPOSAL**	• migration routes of the Caribou would be blocked by IBT canals and dams
U.K.	Ely Ouse to Essex	• reduced nesting success of birds in headwater region of the Stour, due to temporary drying up of the river during shut-downs
U.S.A.	Los Angeles Aqueduct	• reduction in water levels endangered the donor Mono Lake’s suitability as a nesting and feeding area for migratory waterfowl

The Namibian ENWC (Section 2.1.3; Figure 2.4) has been severely criticised for its design due to the fact that it consists in part of a 203 km-long open concrete canal. Estimates of the number of animals that fall into the canal are as high as 17 500 per year (these include large mammals and smaller reptiles), although crossing points are provided and sloping ramps are being installed. The ideal solution would have been for the canal to be covered. However, the cost was deemed prohibitive at the time (Comrie-Greig, 1986; Jones, 1987; Petitjean and Davies, 1988a,b). Attention has focused on large-animal deaths, with no cognisance of the myriad smaller organisms (vertebrates and invertebrates) that fall into the canal, with obvious consequences for water quality. The option of covering the canal is now being contemplated once again, at much higher costs than if this had been done in the first place (Davies *et al*., 1992).

Between 1970 and 1980, Los Angeles diverted an average of 123 x 10^6 m^3 yr^{-1} or about 83% of the average flows of principal tributaries, from Mono Lake in southern California through the Mono Craters Tunnel (Roos-Collins, 1993). As a result of these transfers, the water level in Mono Lake decreased by 12 m causing increased salinity levels that endangered the lake’s suitability as a nesting and feeding area for migratory waterfowl.

Temporary shut-downs of the Ely Ouse to Essex Scheme in the U.K. (Section 2.5.2; Figure 2.23) have resulted in the drying out of the upper reaches of the recipient River Stour. This has had a negative impact on the nesting success of ducks and kingfishers in the area (National Rivers Authority, 1994).

3.4.6 Plants

Most of the literature relating to IBTs and their effects on plant groups, deals with the transfer of diatoms and macrophytes through transfer schemes in the U.K. Holmes *et al.* (1972) undertook a survey of the River Tyne (Kielder Water Scheme; Section 2.5.2; Figure 2.23) in an attempt to predict the floristic and algal changes that would occur with the transfer of water to the Wear and Tees rivers. They suggested that the Wear would be subject to recurrent inoculation by several species presently absent but that it was unlikely that any of these would become pests. Later, Belcher and Swale (1979) made an interesting observation while studying the distribution of the coastal diatom, *Actinocyclus normanii,* in freshwater systems in England. With particular reference to reservoirs, it was noted that these diatom populations appeared to be non-viable, disappearing after only a few generations. The diatom owed its presence in these reservoirs to the water transfers which feed them, and which periodically re-inoculate the waters. The diatom was found only in reservoirs filled with water pumped from donor rivers. Belcher and Swale (1979) postulated that if the transfers of water were to cease, these populations would disappear.

Due to water transfer through the Ely Ouse to Essex Scheme in the U.K. (Section 2.5.2; Figure 2.23), transfers of *Stephanodiscus* blooms between the catchments gave rise to public complaints about potable water quality, and transfers were halted (Guiver, 1976; Jollans and Zabel, 1982). Furthermore, prior to water transfers the dominant diatom in the River Stour, one of the recipients of the Ely Ouse to Essex Scheme, was the alga *Melosira* sp. The inoculation provided by the substantial transfer of *Stephanodiscus* from the Ely Ouse appears to have caused a shift in dominance to the latter algal species (Guiver, 1976). Discolouration of the Essex River water due to the introduction of nutrient- and algal-rich water from the Ely Ouse has led to reductions in light intensity and thus the loss of macrophytes and macroinvertebrate taxa. This reduction in water quality could possibly account for observed reductions in *Gammarus* (a genus of amphipod) numbers following an experimental release of Ely Ouse water into a recipient, the River Colne (Boon, 1988; National Rivers Authority, 1994).

In an analysis of the algal characteristics of Silverwood Lake in the U.S.A, Kubumoto *et al.* (1974) noted that some of the species occurring in the lake appear to have been transported from the north through the California Aqueduct, a component of the CSWP (Section 2.2.2.; Figure 2.12).

Turning to macrophytes, Holmes and Whitton (1977) conducted a macrophyte survey of the River Tees, a recipient of the Kielder Water Scheme in the U.K. (Section 2.5.2; Figure 2.23), in order to describe the changes in the river since 1965. They attributed the upstream spread of four submerged angiosperms to river regulation, at Cow Green Reservoir. Three species, *Potamogeton crispus* (pondweed), *Zannichellia palustris* and *Myriophyllum spicatum* have spread upstream from the lower Tees, while *Ranunculus cillatus* var. *calcareus* was a new record in the river and presumed to be an invader. They also stated that transfer of water from the Tyne to the Tees is likely to cause further changes, since four Tyne species (found upstream of the abstraction point of the transfer scheme) are absent in the Tees, and another 22 are found only in the lower reaches of the Tees.

In southern Africa, the clarity of the water released from Katse Dam in Lesotho (LHWP) (Section 2.1.3; Figure 2.4) could lead to increased light penetration, and this, combined with the more constant flow below the dam, will encourage the growth of various macrophytes, such as filamentous algae (especially in riffle areas), *Potamogeton* sp. (pondweed) and *Typha* sp. (bulrush) (Chutter, 1993). Furthermore, it is possible that the transfer of clear water to the Vaal River will lead to decreased turbidities in the Vaal Reservoir and, thus, increased plant production.

It has been noted by Cugley (1988) that water transferred from the Murray River, Australia, to reservoirs in the Adelaide/Whyalla area (Section 2.4.1; Figure 2.20), has elevated nutrient levels in these recipient systems. This has been associated with an increase in blooms of toxic cyanophytes in Adelaide water storages over the past 10-15 years.

A major problem that is being experienced in many countries in Africa is the spread of invasive aquatic macrophytes (e.g. Davies and Day, 1998). The construction of IBTs not only links previously isolated infestations of plants, but also provides new habitat that is possibly suitable for establishment of these species. This has been found true in Egypt, where the provision of suitable habitat within the Jonglei Canal (Section 2.1.1; Figure 2.1) has increased the spread of the water hyacinth (*Eichhornia crassipes*) and the water cabbage (*Pistia stratiotes*) (Brown *et al*., 1984).

Table 3.11 The effects of IBTs on plant taxa.

Country	Scheme	Effects (actual and potential)
Australia	Lower Murray River Transfers	• water transfers from the Murray River have elevated nutrient levels in recipient reservoirs in the Adelaide/Whyalla area, leading to increases in blooms of toxic blue-green algae
Southern Africa	LHWP	• the clarity of the water released from Katse Dam could lead to increased light penetration, which will encourage the growth of various macrophytes, such as filamentous algae, *Potamogeton* spp. (pondweed) and *Typha* spp. (bulrush) • it is also possible that the transfer of clear water to the Vaal River will lead to decreased turbidities in the Vaal Reservoir and, thus, increased plant production
U.K.	Kielder Water Scheme	• populations of diatoms in recipient reservoirs owe their persistence to re-inoculation from IBTs • disjunct distributions of some macrophyte species in the donor Tyne River, and recipient Wear and Tees rivers could be mixed as a result of the IBT
U.K.	Ely Ouse to Essex Scheme	• transfers of *Stephanodiscus* blooms between the catchments gave rise to public complaints about potable water quality • shift in dominance occurred, from a *Melosira* sp.-dominated system, to one dominated by *Stephanodiscus*
U.S.A.	CSWP	• some of the algal species occurring in Silverwood Lake appear to have been transported from the north through the California Aqueduct

3.5 Estuarine and Coastal Implications

Due to the fact that water transfers can alter the hydrology, geomorphology, and water chemistry of a river, such alterations can affect estuaries. In the U.S.A., for example, the Santee-Cooper Diversion Project (Section 2.2.2; Figure 2.13) changed the estuary at the mouth of the Cooper River from a vertically well-mixed estuary to one that is stratified. Remaining in North America, Rozengurt *et al.* (1985), in a review of the ecological impacts of the CSWP (Section 2.2.2.; Figure 2.12) on the River-Delta-Estuary Sea ecosystems of San Francisco Bay, have outlined a variety of serious effects of this scheme on fish populations. Substantial reductions in freshwater flow to San Franscisco Bay of up to 63% of annual runoff, have resulted in massive reductions in fish populations. Chinook salmon (*Oncorhyncus tshawytscha*) decreased by 30%, while striped bass (*Morone saxatilis*) decreased by 80%. The economic impact of these losses was estimated to be about US $1.3 billion (Rozengurt *et al.*, 1985).

The capacities of the reservoir storages of the Snowy Mountains Scheme in Australia (Section 2.4.1; Figure 2.20) are so large that spills from the lowest dam have occurred in only seven of 288 months (1970 to 1995), and as a result of the diversions, concern has been expressed about the progressive upstream movement of the salt wedge in the lower reaches of the Snowy River. Furthermore, suspended sediment yields immediately below the lowest dam on the Snowy River decreased by 85% after closure of the first dam, and then by a further 99% after completion of the Scheme (Terrazolo, 1990). This is likely to have effects on deposition and erosion at the river mouth.

Siltation in the lower reaches of the Yangtze River in China was expected as a result of the decreased flow in the river due to the East Route diversion, especially during low-flow months (Changming and Dakang, 1987). This is likely to have detrimental effects on the Yangtze estuary, and estuarine and brackish water fish could also negatively be affected (Xuefang, 1983). In Iraq, the coastal marshes of the Tigris and Euphrates rivers are threatened by the almost total diversion of the flow of the Euphrates and many of its tributaries that carried floodwaters to these marshes (Section 2.1.1; Figure 2.2). In addition, abstractions from the Euphrates by Turkey in order to fill the relatively recently completed Ataturk Dam have demonstrably reduced the flow of the river to the marshes by 10% between 1985 and 1990 (Pearce, 1993a). The marshes are regarded as the most important wetland bird habitat in the whole of Eurasia with millions of waterfowl feeding on the fish and invertebrates of the marshes every year. The area is not declared under the Ramsar Convention and its loss will be measured on an inter-continental, if not on a global scale.

Table 3.12 A list of the estuarine and coastal implications of IBTs.

Country	Scheme	Effects (actual and potential)
Australia	Snowy Mountains Scheme	• flow reductions in the Snowy River are leading to a progressive upstream movement of the salt wedge in the lower reaches of the river • a 99% reduction is suspended sediment yields below the IBT is likely to have effects on deposition and erosion at the river mouth
China	East Route **PROPOSAL**	• siltation in the lower reaches of the donor Yangtze River was expected to have detrimental effects on the Yangtze estuary, and estuarine and brackish water fish could also negatively be affected
Iraq	Euphrates diversions	• the coastal marshes of the Tigris and Euphrates rivers are threatened by the almost total diversion of the flow of the Euphrates and many of its tributaries – these marshes are important as wetland bird habitat
U.S.A.	Santee-Cooper Diversion Project	• changed the estuary at the mouth of the Cooper River from a vertically well-mixed estuary to one that is stratified
U.S.A.	CSWP	• reductions in freshwater flow to San Franscisco Bay have resulted in a 30% reduction in numbers of chinook salmon, *Oncorhyncus tshawytscha,* and an 80% reduction in numbers of striped bass, *Morone saxatilis* • economic impact of these losses was estimated to be about US$1.3 billion

4. A BRIEF OVERVIEW OF THE SOCIO-ECONOMIC, CULTURAL AND POLITICAL EFFECTS OF IBTS

4.1 Introduction

It is obvious that the motivation behind the transfer of water is to provide water to human communities, in order to improve their quality of life, or to facilitate further municipal, agricultural, or industrial development. However, many of the ecological effects of IBTs, described in the previous chapter, will have detrimental impacts on the socio-economic, cultural and political aspects of these human communities (e.g. Howe and Easter, 1971; Howe, 1978; Howard, 1991; Davies *et al*., 1992). In some cases, the health of individuals or communities may be affected.

This chapter provides a number of examples of the actual and potential effects of IBTs, as they relate to human communities. In many instances, these effects have already been detailed in Chapter 3, as it is difficult to separate ecological effects from those associated with socio-economics, human culture and politics. Indeed, the links between these effects have implications for the planning and management of IBTs, and affected human communities will inevitably benefit from the diminution of the ecological damage caused by transfer schemes.

4.2 Socio-economic Effects

The most obvious economic implications of water transfer are the costs of such schemes. These include the capital costs of construction and operation, including intake and discharge structures, pump stations, pipes and tunnels. In addition, capital costs include property acquisition, permitting, engineering, legal fees, and administrative costs. Litigation costs often can be extensive. As the number of claims on a given volume of water increases, the costs of identifying and negotiating with multiple users also increase, such that the cost of negotiating with owners or claimants may eventually exceed the potential benefits of the transfer (Cox and Shabman, 1982). Furthermore, the high financial costs of large-scale IBTs can lead to sharp increases in water tariffs. While acknowledging the necessity of paying the appropriate price for a precious resource, disadvantaged communities might struggle to afford the high costs of water transfers.

This is especially true of poor communities in South Africa who, until fairly recently, have lived without water supply and sanitation services. With the construction and operation of the LHWP in neighbouring Lesotho (Section 2.1.3; Figure 2.4), the costs of importing water from this country have resulted in substantial increases in water tariffs, which some of the recipient communities cannot afford. These communities have objected strongly to the water tariffs, and have demanded cheaper water conservation measures (Residents of Alexander Township, South Africa, *in litt*., April 1998; Aslam, 1998; Ballenger, 1998).

Economic benefits of water transfer often are provided as justification for transfer projects. Direct economic benefits might occur through increased agricultural production, or increased municipal growth. The economic consequences of water transfers also include implications for incomes, jobs, and business opportunities that are directly or indirectly reliant on IBTs. Water transfers alter water supplies and can thus negatively alter economic benefits related to water supplies, such as money spent on boating, fishing, hunting, and camping. Many communities rely on water-dependent tourism as a significant source of income for local residents. The Lake Texoma-Lake Lavon Water Transfer Project in Oklahoma-Texas (Section 2.2.2; Figure 2.12) offers an example of the potential for negative economic change in a local community as a result of water transfer. Concerns relating to the Lake Texoma water transfer included the potential for decline in the recreationally important sport fisheries of Lake Texoma, valued at about US \$25 million yr^{-1} in direct expenditures to the local economy (Schorr *et al*., 1995). Potential impacts of sport fishing expenditures included up to US \$57 million yr^{-1} in total business sales, US \$23 million in personal income, and 718 jobs. Thus, changes to the sport fishery of Lake Texoma as a result of water transfer would have a significant impact on the local economy. However, a study indicated that short-term withdrawal rates of up to 83×10^6 m^3 yr^{-1} under the proposed operation of the water transfer would not significantly alter water quality or habitat conditions needed to support sport fishery populations in Lake Texoma (Schorr *et al*., 1993).

There are several other examples of the effects of IBTs on fisheries. As a direct result of the Churchill River Diversion in Canada (Section 2.2.1; Figure 2.9), increased leaching of local soils, which contain high levels of mercury, led to increases in the mercury content of fish flesh, in addition to a reduction in the quality of whitefish catches, with obviously deleterious consequences for local commercial fisheries. The increased mercury levels now exceed Canadian marketing limits for both pike and walleye, but should decrease once erosion has stabilised and turbidity has decreased. In the meantime, a financial settlement has been made with the affected parties (Day, 1985). Few fisheries effects have been reported in the rivers associated with the Churchill River Diversion, due primarily to the previous lack of exploitation of these reserves by sports fishermen. However, development of fisheries in the Split and Stephens lakes cannot be undertaken until the mercury problem subsides (Day, 1985).

The most significant impact of the SCAP diversions (Russia; Section 2.3.1; Figure 2.16) on the donor area would be the effect on the commercially exploited fisheries (salmon, sturgeon, whitefish) which have, in the past, provided catches of up to 53 000 tonnes yr^{-1}. Loss of feeding and breeding areas, pollution, altered hydrological regimes and loss of wintering areas, to where fish migrate in order to avoid anoxic winter conditions, would result in a 14 to 17% reduction in catch for the first phase alone (Voropaev and Velikanov, 1985). Apart from fisheries losses, the reduction of natural swampland area in the donor area of SCAP, would have reduced the marsh-bird population which normally thrives in this area, and which is economically exploited. Remaining in Russia, the Pechora River and its bay, donor to the ETP (Section 2.3.1; Figure 2.16), constitute one of the most important Atlantic salmon fisheries of the region, contributing 60% of the regional catch. The projected reduction in catch due to the proposed third-stage diversion of water from the Pechora to the Volga, is of the order of 50% (Voropaev and Velikanov, 1985; Micklin, 1986). The status of the Caspian Sea, a proposed recipient of the ETP, as the largest producer of sturgeon in the former USSR, is threatened by increasing salinisation (Micklin, 1986; *New Scientist*, 1988). This is as a result of the operation of hydro-electric projects, and the annual diversion of some 40×10^9 m^3 from the rivers that feed the sea, for industry and agriculture. In addition, catches of species of bream, carp, zander and vobla have dropped by 80%, and the less economically viable sprats make up 80% of the catch. Shad and Caspian salmon have all but disappeared.

The proposed East Route in China (Section 2.3.2) would have transferred water through a series of shallow lakes, Hongze, Luoma, Dongping and Nansi, which serve as important freshwater fisheries and it is feared that the high water levels resulting from the use of these lakes as a transfer route could reduce their productivity (Xuefang, 1983). These lakes are also rich growing areas for various economically important plant species, such as *Phragmites* reeds, lotus root, wild rice, and water chestnuts.

Other economic activities have also been affected by IBTs. For example, the National Water Carrier in Israel (Section 2.1.1; Figure 2.2) diverts Jordan River water away from the country of Jordan, and the Dead Sea. As a result, the surface area of this inland sea has shrunk by approximately 300 km^2, which represents 30% of its original area. This dramatic reduction in area has left factories, that extracted potash and other salts from the seawater, stranded several kilometres from the edge of the sea (Pearce, 1995b).

The reduction in water quantity in donor systems can also lead to municipal water supply problems in the donor catchment. In China, for instance, reduced dry-weather flows, as a possible result of the diversion of water along the East Route (Section 2.3.2; Figure 2.17), have raised fears of a substantial reduction in freshwater supplies to the industrial, agricultural and domestic water for Shanghai Municipality (Yuexian and Jialian, 1983).

Many of the world's largest transfer schemes involve navigable rivers. Thus, alterations in water quantity and increased siltation associated with IBTs (Section 3.2.1, 3.2.2), could have detrimental effects on the navigational use of rivers. For example, altered flows, sediment transport and tidal gradients in the Yangtze estuary will adversely affect navigation in these parts of the river and estuary. This is despite the predictions of Yuexian and Jialian (1983), who, in their review of the probable effects of China's East Route water transfer, anticipated that the use of the Yangtze as China's main navigation channel would not be affected by this transfer, even when all three proposed routes are operational. In Russia, a 43% reduction in flow in the Upper Sukhona, donor to the European Transfer Project (ETP) (Section 2.3.1; Figure 2.16), would have resulted in difficulties for navigation and for timber rafting on the river (Voropaev and Velikanov, 1985; Micklin, 1986). It was also observed that, with the development of NAWAPA, many of Canada's transcontinental transport links would have been cut by the proposed reservoirs (Micklin, 1977) (Sections 2.2.1, 2.2.2).

Table 4.1 A summary of the socio-economic effects of IBTs described in the text.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Socio-economic effects			
Canada	Churchill River Diversion	• leaching of soils containing mercury led to increased mercury levels in fish, and reduced whitefish catches	Development of fisheries in affected lakes will have to wait for mercury levels to subside
China	East Route **PROPOSAL**	• feared that productivity in shallow lakes to be used along transfer route, which serve as important freshwater fisheries and which are also rich growing areas for various economically important plant species, will be reduced as a result of high water levels • altered flows, sediment transport and tidal gradients in the donor Yangtze estuary will adversely affect navigation in these parts of the river and estuary • fears of substantial reduction in freshwater supplies to the industrial, agricultural and domestic water for Shanghai Municipality	
Israel	National Water Carrier	• diversion of the Jordan River away from the Dead Sea has resulted in a reduction of surface area of this inland sea by 300 km^2, or 30% of its original area, leaving factories, that extracted potash and other salts from the seawater, stranded several kilometres from the edge of the sea	
Russia	SCAP **PROPOSAL**	• loss of feeding, breeding and wintering areas, pollution, altered hydrological regimes would lead to a 14 to 17% reduction in commercially exploited fish catches for the first phase alone • reduction in commercially exploited marsh-bird populations expected in donor areas	
Russia	ETP **PROPOSAL**	• projected 50% reduction in salmon catch due to proposed third-stage diversion of water from the Pechora to the Volga • in the proposed recipient Aral Sea past diversions have led to an 80% drop in the catches of bream, carp, zander and vobla, and now 80% of the fish caught are the less economically viable sprats; the ETP would alleviate this • 43% reduction in flow in the donor Upper Sukhona River would have resulted in difficulties for navigation and for timber rafting on the river	
Southern Africa	Lesotho Highlands Water Project	• strong objection to the increase in water tariffs, and lack of water demand management strategies which would reduce the tariff increment	
U.S.A.	Lake Texoma-Lake Lavon Transfer	• potential for decline in the recreationally important sport fisheries of Lake Texoma, valued at about US \$57 million yr^{-1} in total business sales, US \$23 million in personal income, and 718 jobs	
U.S.A.	NAWAPA **PROPOSAL**	• many of Canada's transcontinental transport links would have been cut by proposed reservoirs	

4.3 Aesthetics and Cultural Implications

Water transfers can affect the cultural integrity of ethnic communities. In many cases, there are strong bonds between water and the cultural values of ethnic communities. The loss of control over water resources is more than just the loss of control of a resource as a commodity of economic value. Water transfers can infringe on all cultural values associated with the water itself. A notable example of cultural implications of water transfer is evidenced by the Hispanic and American Indian communities of northern New Mexico (U.S.A.) and the San Juan-Chama Project (Section 2.2.2; Figure 2.12). The San Juan-Chama Project was constructed to transfer water from the San Juan River of the Colorado River Basin to the Rio Chama of the Rio Grande Basin. Approximately $0.5 \times 10^9\ m^3\ yr^{-1}$ is transported across the Continental Divide through a series of diversion canals and tunnels. Contrary to regional water demand, the demand for water in the area has developed primarily in response to local urban and recreational needs. Many of New Mexico's cities are located along the Rio Grande, including Taos, Sante Fe, and Albuquerque. In addition, recreational use, particularly that associated with the increased number of ski resorts, places demands on Rio Grande water. Conversely, agricultural use is marginal and is associated with traditional cultural lifestyles of surrounding ethnic communities.

Three distinct cultures - American Indian, Hispanic, and Anglo - compete for limited water resources in New Mexico. Each ethnic group has developed distinct concepts about water use: many American Indians view water in a spiritual context; Hispanics tend to view it as a community resource to be shared equitably; Anglos view water as an economic commodity. Many of the American Indian and Hispanic communities had well-established water allocation systems in place prior to State systems. The San Juan-Chama Project threatened water availability at important American Indian religious sites. Many Hispanic communities were formed around the development and maintenance of irrigation ditches. Reduced water availability to these irrigation ditches threatened not only the existence of the communities, but imposed a system of individual water-use priorities on a tradition of communal sharing of surpluses and shortages. The National Research Council (1993), in reviewing the San Juan-Chama Project, suggested that due consideration be given to cultural values of water allocation, and, if necessary, that historical and cultural zones be established to minimise potential negative impacts of water transfers to ethnic communities.

The California State Water Project (CSWP) (Section 2.2.2.; Figure 2.12) draws water from the Sacramento River, and this has resulted in the damming of the scenic Feather River. To add to this aesthetic and recreational impact, it is likely that it will be necessary to implement further water transfers from the Klammath, Trinity and Eel river systems to the Sacramento River, in order to maintain the San Francisco Bay delta. These three rivers are in the north of California, which is an area considered to be one of the last natural refuges in California. Development of these rivers would affect many aspects of these sensitive systems (Ortalano, 1979). Further north, no compensation was made to the Canadian Parks Branch, for the loss of approximately 350 000 ha of Tweedsmuir Park, a popular tourist destination in Canada, after inundation due to the development of the Kemano Diversion (Day, 1985) (Section 2.2.1; Figure 2.9). The construction of this IBT also led to problems associated with the way in which the local Cheslatta Indians were displaced from their reservations (Day, 1985). At least ten Cheslatta Band reservations occupied land in the area which was to be flooded by the lakes and spillways associated with the Kemano Diversion. Alcan, the developer of the IBT (Sections 2.2.1 and 3.4.2), held a meeting with the Cheslatta Indians three days before flooding began. A settlement was reached three weeks later, in which the company would erect two monuments above the floodline to mark the location of two graveyards, each flooded family would be compensated for their loss of land, and Alcan would assist in moving them from the area. The Minister of Indian Affairs approved the sale of Cheslatta land to Alcan seven months after their evacuation, while a water licence was granted to Alcan four months after flooding began. The Cheslatta Indians had to abandon their traditional occupations of hunting, trapping and fishing, and were afforded meagre compensation (Day, 1985).

The inundation of land is often associated with IBTs, and there are a few records in the literature of cases where this has resulted in the loss of sites of archaeological or anthropological interest. Indeed, the main concern with respect to the ETP proposals in Russia (Section 2.3.1; Figure 2.16) was anthropological, and a national issue was made of the preservation of historically significant sites such as the Ferapontovo and Kirrilov-Belozerro monasteries, the Sophia Cathedral, and the settlements of Vologda, Kargopol', Beloozersk and Tot'ma, which were thought to be threatened by the likely raising of groundwater levels and consequent flooding. Public concern was successful in forcing water planners to divert the transfer route 15 to 20 km away from these sites (Voropaev and Velikanov, 1985; Micklin, 1986). In Canada, traditional sites for Indian and European settlements on river banks have been lost as a result of the James Bay Project (Section 2.2.1; Figure 2.9), which has led to a rise in water levels in the recipient La Grande Rivière basin (Day, 1985). Historically, these waterways were routes of transportation for early settlers, and thus villages and towns were located along the banks of the river and its lakes.

Table 4.2 A summary of aesthetic and cultural effects of IBTs.

Country	Scheme	Effects (actual and potential)	Outcome (if any)
Aesthetics and Cultural Implications			
Canada	Kemano Diversion	• no compensation given for the loss of approximately 350 000 ha of Tweedsmuir Park, a popular tourist destination in Canada • Cheslatta Band Indians living in the area to be inundated had to abandon traditional occupations of hunting, trapping and fishing, and were afforded meagre compensation • the developer met with these communities 3 days before flooding began	
Canada	James Bay Project	• traditional sites for Indian and European settlements on river banks have been lost as a result of raised water levels in the recipient La Grande Rivière basin	
Russia	ETP **PROPOSAL**	• historically significant sites such as the Ferapontovo and Kirrilov-Belozerro monasteries, the Sophia Cathedral, and the settlements of Vologda, Kargopol', Beloozersk and Tot'ma, were thought to be threatened by the likely raising of groundwater levels and consequent flooding	planners diverted the transfer route 15 to 20 km away from these sites
U.S.A.	San Juan-Chama Project	• diversion from donor San Juan River threatened water availability at important American Indian religious sites • reduced water availability to communal Hispanic irrigation ditches threatened the existence of these communities, and imposed a system of individual water-use priorities on a tradition of communal sharing of surpluses and shortages	National Research Council suggested that due consideration be given to cultural values of water allocation, with the establishment of historical and cultural zones, if necessary
U.S.A.	CSWP	• led to damming of scenic Feather River • possible further impoundment of sensitive Klammath, Trinity and Eel river systems, for southward diversion in order to maintain the San Francisco Bay delta	

4.4 Political Implications

Although economic implications of water transfers are complex and difficult to assess, political implications are perhaps the most complex aspects of transfer projects (Biswas, 1978). Many rivers in the world are shared resources, flowing through or between more than one province or country (e.g. Davies and Walker, 1986). In addition, excessive water consumption, climatic stochasticity, rapid population growth and inefficient water infra-structure serve to increase the already severe pressures on river ecosystems in many parts of the globe. As stresses on rivers continue to increase, the re-distribution of water is rapidly becoming more complex and extensive (Snaddon *et al*., 1998). The transfer of water has a disturbing and largely unaddressed potential for severe ecosystem and socio-economic perturbation, and thus for intra- and international conflict (see Ortalano, 1978; Cox *et al*., 1985; Day, 1985).

A major factor which has been identified by many as the source of a number of political problems associated with IBTs, is the nature and jurisdiction of the institutional structures responsible for water resources planning and management (Fox, 1973; Cox *et al*., 1985; Day, 1985; Shiklomanov, 1985; Snaddon *et al*., 1998). In many cases, the river basin is considered to be the logical unit of management. However, political boundaries seldom coincide with watersheds, and IBTs will, in most cases, cross catchment boundaries, and sometimes, political borders. Thus there can be a lack of conformity in approaches towards water resources management which could lead to conflicting allocations of resources. For instance, political conflicts often arise as a result of opposition to transfer by the parties representing the areas of origin.

Probably the earliest IBT proposal in England was rejected during its passage through the House of Commons, as a result of a public outcry concerning the consequences of the scheme for the donor system, the River Thames (Sheail, 1984). The 1855 Bill proposal for the transfer of one million gallons of springwater a day (1.6×10^6 m^3 yr^{-1}) from the headwaters of the Thames to the Severn River Valley, raised fears that since none of the transferred water would return to the Thames, not only would the water level in the Thames drop, making navigation more difficult, but also that reduced flow would result in less efficient dilution of effluents, particularly sewage, which already entered the river. Interestingly, this was probably one of the earliest public objections to an IBT on the grounds of the potential environmental effects of the scheme. As motivation for the transfer, the Right Honourable Member of Parliament for Birmingham, Sir Joseph Chamberlain, stated that the water "...comes from Heaven and goes to the sea, and no more belongs to Welshmen than anybody else who stands in need of it."

Until recently in South Africa, national legislation provided no guidance for the planning and implementation of IBTs. In fact it was stated by the Department of Water Affairs in a book entitled "*Management of the Water Resources of the Republic of South Africa*", that "There are, in the Republic, fortunately no legal restrictions for the transfer of water from one river basin to another." (Department of Water Affairs, 1986a). As a result, no restrictions have been placed on the construction of transfer schemes in this country, and there has been no protection given to donor catchments. However, a comprehensive and consultative law review process has recently culminated in a new Water Bill. The new legislation states that after providing for the Reserve - this is an amount of water to be preserved for basic human requirements and the ecological requirements of the freshwater source - and international obligations, the basis for granting a license to use water available in the area, will be to achieve beneficial use in the public interest which will include consideration of the need for programmes of corrective action. Any allocation of water use, over and above the Reserve, for example for transfers to other basins, will thus be subject to conditions which ensure that basic human needs and ecological requirements in the donor catchment are met (Department of Water Affairs and Forestry, 1997, 1998).

Furthermore, all forms of river regulation, including IBTs, will have to meet special planning requirements and implementation procedures, which must involve agencies from both the donor and recipient catchments. Catchments to which water will be transferred will have to show that the water currently available in that catchment is being optimally and beneficially used, and that reasonable measures to conserve water are in force before any water can be allocated elsewhere (Department of Water Affairs and Forestry, 1997, 1998). On the international level, a negotiated protocol on shared watercourses in southern Africa has only recently been developed (Southern African Development Community, 1995) and is in the process of ratification by countries in the region (Minister Maro, SADC, personal communication, September 1998). A lack of such agreements in the past has led to current problems with water allocation. For example, the abstraction of water from the Orange River through the LHWP on such a large scale has serious political implications given current commitments on the part of South Africa to supply Namibia with water from the lower Orange River. After construction of the LHWP was well underway, Namibia had not completed a comprehensive assessment of its national water requirements, both current and predicted and, thus, Namibia's allocation of water from the lower Orange was based on conjecture (Martin, 1993). Namibia presently uses 20×10^6 m^3 yr^{-1} from the Orange River and irrigates 2000 ha of land adjacent to the river (Martin, 1993). According to the SADC protocol, Namibia now has protection as a downstream user of water from the Orange River, and this could have implications for the total amount of water diverted by the LHWP.

The Constitution of the USA does not directly address water resources or their development. However, sections of the Constitution do address the right and duty of the Federal government to provide for the general welfare of the Nation and regulate the movement of commerce across State lines. These sections have been interpreted by courts to authorise Federal involvement in water transfers, particularly across State boundaries. For example, the U.S. Supreme Court ended ten years of litigation between Arizona and California by concluding that the water supply of the Colorado River was not large enough to meet water demands of both States. This court decision provided the opportunity for those States to seek supplementary water supplies outside the Colorado River Basin (Biswas, 1978).

In 1968, the United States Congress announced a ten-year moratorium on the investigation of any diversions from the Columbia River (Johnson, 1971). This was in order to give the Pacific Northwest (the donor) time to assess present and future water needs, and to determine whether or not there was a surplus of water available for export. During the ten years, one of the issues that was explored was the protection of the "area-of-origin". The governments of the states of the Pacific Northwest in the United States, accompanied by a powerful public lobby, consistently opposed the transfer of water out of the Columbia River Basin (Howe, 1978). Senator Jackson of Washington has stated: "The people of the Northwest deeply believe that before any other region asks for a study of the diversion of the Columbia River, such region must first establish that it actually needs additional water....Can sufficient water be secured through conservation and reuse?...".

The State of Delaware attempted to prevent New York City from transferring water out of the Delaware River catchment, even though this river originates in New York State before flowing into the State of Delaware. To settle the dispute, a decree of the U.S. Supreme Court permitted the City to divert water while requiring the City to meet minimum releases from its reservoir system in order to meet downstream water demands (Howe, 1978).

The "appropriation" system of the Western United States has never made any distinction between the use of water within or outside a catchment (Johnson, 1971). As a result, communities in many donor catchments have expressed concern over the lack of protection for their catchments. A variety of State statutes (California, Colorado, Nebraska, Texas and Oklahoma) and one inter-state compact (made in 1929, between the upper and lower basin states of the Colorado River), were created to give a degree of protection to catchments of origin (donors). In general, this legislation serves to protect, or to reserve water for use within the donor catchments, and also to guide the design of IBT projects in order to ensure that a donor catchment is left in a better position in terms of water-supply infrastructure than it was before diversion. This legislation is described in greater detail by Johnson (1971) and Cox (1991).

Detailed economic analyses of IBTs has been obligatory in the USA since the early 1930s, but evaluation of environmental effects has only been required in legislation since 1969 (Ortalano, 1978; Shiklomanov, 1985). In addition, the USA has a vast array of environmental laws at Federal and State levels that influence water-resource development and that play a significant role in determining the construction and implementation of water transfers (Micklin, 1985). In Massachusetts, for example, the Interbasin Transfer Act (Massachusetts Laws 1983) provides a safeguard against unnecessary water transfers (Platt, 1995). The legislation stipulates that the minimum flow requirements (unspecified, but presumably "ecological requirements"; Platt, 1995) of the donor basin must be met, and that the applicant basin must prove that it has used "every reasonable method to develop and conserve its own in-basin sources before looking outward." (Massachusetts Water Resources Authority, 1990). Other legislation deals with the protection of fish and wildlife, water quality, endangered species, scenic and wild rivers, and coastal areas. Such laws can serve to minimise potential negative environmental effects of water transfers.

In Canada, national water resources are protected by a federal policy preventing water transfer to the United States, until the national supply-demand scenario has adequately been addressed (Howe, 1978; Day, 1985). Towards the mid-1960s, Canada took a strong stance in opposing any transfer of water to the USA, stating that "...Canadian water is for Canadian development." (Howe, 1978). It is possible, however, that this situation will change with the 1994 implementation of the North American Free Trade Agreement (NAFTA). Under this legislation water can be viewed as "goods", which can be traded between Mexico, the USA and Canada. This would remove virtually all of the international political obstacles to large-scale water transfers, and make it difficult to prevent the construction of projects like NAWAPA through national or provincial regulations.

5. IBT PLANNING AND MANAGEMENT

5.1 Introduction

In the vast majority of cases, the emphasis in planning IBT projects has been placed on the engineering and economic aspects associated with them. Most water transfers have been perceived by governments and engineers as technological and economic challenges and, consequently, little or no environmental planning has accompanied most of the technical and economic feasibility studies that have been carried out as a matter of course (e.g. Greer, 1983; Day, 1985; Shiklomanov, 1985; Platt, 1995). However, and inevitably, many problems have arisen from such limited planning and hasty development, many of which are associated with the environmental and socio-economic consequences of water transfers (see Chapters 3 and 4). Public, and often political opposition to IBTs, and other large-scale river regulation, is on the increase, and the need for more sensitive planning is rapidly becoming apparent worldwide (Loh and Gomez, 1996; McCully, 1996; Davies and Day, 1998).

In terms of the social and economic effects of IBTs, the donor catchment is often disadvantaged, with most, if not all, benefits going to the recipient. However, as far as environmental effects are concerned, the effects of water transfer on the recipient, the donor and often on the transfer route, can be equally severe, but are seldom given equal consideration, if any at all (Snaddon *et al*., 1998). In order to address the concerns associated with IBTs, many of which have been raised in the previous chapters, the planning phases of a project must take all of the components into account and give them equal weighting.

This chapter examines current IBT planning in various countries around the world, and summarises some of the problems and conflicts that have arisen. Lastly, a list of recommendations for the planning and management of IBTs is provided.

5.2 Problems Associated with IBT Planning

Many of the problems associated with the implementation of water transfer projects relate to the planning phases of these schemes (e.g. Thomas and Box, 1969; Greer, 1983; Cox *et al*., 1985; Shiklomanov, 1985; Davies *et al*., 1992), such as:

- a lack of comprehensive environmental assessments;
- the subordination of environmental assessments to the technical and economic aspects of IBTs;
- a lack of co-ordination between environmental assessments (where they do occur), and other aspects of IBT planning, such as the technical and economic studies; and
- a general geographical bias towards recipient catchment/s, at the expense of donor system/s, while transfer routes are effectively ignored.

The first two of these problems were evident during the planning of the Texas Water Plan (Section 2.2.2; Figure 2.12), in the USA, which was eventually abandoned. In this case, primary attention was given to the technical and economic aspects of the scheme, which involves the transfer of water from the Mississippi River, to western Texas and New Mexico. Environmental studies were initiated in response to completion of the engineering and economic feasibility phases, while a third step consisted of a revision of the initial technical plan to accommodate those environmental concerns that were perceived more as political obstacles than as ecologically necessary modifications (Greer, 1983). The Texas Water Plan also provides an example of the fourth problem listed above: water demand, economic and population projections were calculated for Texas, but not for the donor system, the Mississippi Basin (Greer, 1983).

A similar oversight was committed in the Western Cape Province of South Africa, where a regional analysis of available water resources was commissioned in 1984 by the national Department of Water Affairs. An evaluation of the final analysis, the Western Cape System Analysis (WCSA), uncovered the foolishness of excluding one of the Western Cape's major river basins, the Breede River catchment, from such a system analysis. At least three IBTs have been proposed which would transfer water from the Breede River and its tributaries to the Cape Metropolitan Area (Section 2.1.3; Table 2.4), and yet the consequences of these IBTs have not been assessed within the context of the WCSA (Zille Shandler Associates, 1996). Communities, and especially the agricultural community, of the Breede River catchment have called for a moratorium on the impoundment of their rivers until a Breede River System Analysis has been completed. This System Analysis was commissioned in 1999 (Dr C. Brown, Southern Waters Consulting, University of Cape Town, pers. comm.).

A further example of inadequate planning can be drawn from southern Africa. Exploitation of the upper Orange River in Lesotho, in order to supply water to South Africa, *via* the Lesotho Highlands Water Project (LHWP), could ultimately substantially reduce the yield of the downstream IBT, the Orange River Project (ORP) (Section 2.1.3; Figure 2.4) (Davies *et al*., 1992). Furthermore, there is considerable concern that schemes such as the LHWP will divert water from the Northern Cape Province, where the Orange River is the most important and the largest single aquatic ecosystem (e.g. Benade, 1993). Half of the catchment lies within the boundaries of the Province, which contributes only 2% to the MAR of the system. The maintenance of the perennial nature of flow in the middle and lower reaches of the Orange River is thus crucial to the Province.

Globally, several IBT schemes have been abandoned or modified as problems have become apparent, while others have been postponed as a result of the lack of adequate environmental assessments during the feasibility planning stages (e.g. Guiver, 1976; Greer, 1983; Day, 1985; Shiklomanov, 1985). These include (see Chapter 2):

- The transfer from Lake Suldalsvatnet to Hylsfjorden in Norway ceases during June and July during salmon runs in order to protect these economically important species (Nordeng, 1977; Tøndevold, 1984) (Sections 2.5.1 and 3.4.2).

- The McGregor Diversion, Canada, was shelved in 1978 as a result of the possible transfer of both fish and their parasites from the Fraser River to the Arctic-draining Peace River (Arai and Mudry, 1983; Day, 1985) (Sections 2.2.1. and 3.4.3).

- Flow into the Nechako River from the Kemano Diversion, Canada, had to be ensured by a British Columbia Supreme Court injunction, in order to protect sockeye salmon migration routes (Day, 1985) (Sections 2.2.1 and 3.4.2).

- The Ely Ouse to Essex Scheme, in the U.K., was temporarily halted due to the transfer of algal blooms from the point of abstraction (Guiver, 1976) (Sections 2.5.2 and 3.4.6).

- The proposed diversion of Siberian rivers, the Ob and Irtysh, to Soviet Central Asia (SCAP), was "indefinitely postponed" in 1986, as a result of pressure from environmentalists, and economists who were concerned about the feasibility of such a project (Voropaev and Velikanov, 1985) (Section 2.3.1).

- The North American Water and Power Alliance (NAWAPA) scheme was shelved due to the numerous public and political objections to the economic and environmental effects of the project (Micklin, 1977; Shiklomanov, 1985) (Sections 2.2.1 and 2.2.2).

In the past, there has been a lack of transparency in IBT planning. The people who ultimately pay for these schemes, and whose environment is due to be altered, are often not informed of the plans, and are seldom given an opportunity to take part in the planning process. For example, despite a number of calls for action (e.g. Petitjean and Davies, 1988a,b; Davies *et al*., 1992), it was only in mid-1996 that a wide range of organisations and individuals affected by the LHWP in southern Africa (Section 2.1.3; Figure 2.4) were brought together to discuss the project and its consequences (Group for Environmental Monitoring, 1996). Such a workshop should have taken place at the feasibility stage of the planning process (the early 1980s) and not after commencement of filling of Katse Dam (Phase 1A of the project), in October 1995.

5.3 Recommendations for IBT Planning and Management

In this final section, a list of recommendations for the planning and management of IBT schemes is presented. These have been compiled from the literature, and are not listed in any order of priority. It should be noted that more detailed recommendations are presented in a final research report for the Water Research Commission project which has produced this literature review. This final report should be available in early 2000 (Snaddon and Davies, 2000).

- It is clear from the literature that the ecological consequences of inter-basin water transfers are such that great caution is warranted. Data are scarce, but the "precautionary principle" (Department of Environmental Affairs and Tourism, Environmental Policy Discussion Document, 1996) needs to be applied to water-resources planning, allowing for the gathering of data before the feasibility stage of any IBT project. The collection of timely, objective and detailed information on the actual and potential effects of transfers is necessary, in order that all human communities affected by any scheme may assess the IBT in an informed and reasonable manner.

- In addition to the collection of information before the construction of an IBT scheme, all projects should be monitored, in order that the assessment of the effects of IBT can continue through the operational phases (e.g. Davies *et al*., 1992).

- Extant schemes should be re-assessed in terms of their effects, so that detrimental impacts can be minimised through mitigation.

- The environmental aspects of IBTs should not be seen as subordinate to the technical and economic consequences.

- The needs (environmental, social and economic) of all basins concerned in any IBT must be given equal weighting, and must be assessed to the same level for each basin.

- Greater public participation is required during the planning of IBTs, supported by appropriate legislation, and designed to ensure adequate consultation in both the donor and recipient catchments, and communities along the transfer route(s) (e.g. Ortalano, 1978). This has bearing on the environmental consequences of IBTs, as social and environmental issues are intimately linked. Again, the institutional framework for the effective management of this type of participation is crucial to the process. There are examples where public participation is limited to conflict resolution and/or mediation (e.g. Cox *et al*., 1985), but, in most instances, true consultation is favoured (e.g. Platt, 1995). The funding for such participation should usually be provided by the developer (e.g. in Lesotho, the Lesotho Highlands Development Authority; in South Africa, Department of Water Affairs and Forestry).

  The decision to transfer water should not be made by engineers, or water resource managers alone. If a comprehensive and inclusive consultation process were followed, the decision would be reached over time, with the responsibility for determining the optimal solution spread throughout the communities to be affected by the scheme. This would avoid the situation where distant individuals make decisions for local communities, rather than allowing them that power.

- The land-use implications of IBTs, such as effects on soils, waterlogging and groundwater levels can be severe and thus, the regulation and management of land-use should be integrated into IBT planning.

- Monitoring the water quality in transfer structures during periods when an IBT is not active, is important. Equally important is the prevention of stagnant water flushing into recipient rivers.

- The transfer and mixing of previously isolated biota between catchments, and thus the mixing of genetic material and the transfer of exotic and invasive fauna and flora, disease vectors and pests of economic importance, are likely consequences of IBTs. There are examples in the literature of all of these threats (Chapters 3 and 4). This requires great caution and extensive investigation during the assessment of the feasibility of such schemes. Once again, the availability of pre-transfer information from donor and recipient catchments would aid in the assessment of the likelihood of the transfer of fauna and flora.

- Similarly, the likelihood of the transfer of water quality problems, such as cyanophyte blooms, between catchments, should be assessed. The threat of such transfers could be reduced through flexibility in the operational criteria of an IBT scheme, thus allowing for a cease in transfer during periods of risk.

- A botanical investigation to predict the change in vegetative cover under various release strategies would be useful for IBT planning and management. A more definitive prediction of morphological response relies on an improved understanding of the effects of various durations of inundation on those species of trees, shrubs and grass prevalent in the riparian zone of a river.

- The results of work in South Africa indicate that the ecological effects of an IBT from a donor impoundment to a river, are similar to those occurring downstream of an impoundment (Snaddon, 1998). Hence, the recommendation is made that such IBT schemes be assessed using methodologies similar to those utilised in the assessment of river impoundment. For example, methodologies developed for the determination of instream flow requirements (IFR) of rivers (e.g. King & Tharme, 1994; King *et al*., 1995) should be applied to cases where water is transferred into a catchment.

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