AN INVESTIGATION INTO THE REMOVAL OF SEDIMENTS FROM WATER INTAKES ON RIVERS BY MEANS OF JET-TYPE DREDGE PUMPS

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EXECUTIVE SUMMARY

Introduction

Excessive sedimentation at water intakes on rivers causes interruption in water supply and serious abrasion of pumps with consequent high operating costs.

The problem of sedimentation at water intakes on rivers can largely be minimised by appropriate design of the intake structures. Well established sound engineering practices have been developed to ensure sound engineering design of river intake structures. As background to this study, the causes of sedimentation problems and principles of effective design of river intake structures are therefore included in this report.

Sedimentation problems are relatively common in South Africa, especially in the case of smaller[1] intakes on sediment laden rivers. The reason for this is the highly variable flow regime of relatively small rivers on which the sediment prone intakes are located (flow rates in relatively small rivers, usually vary between very low and very high (flash floods) in a season). The consequence of the variable flow regime is significant variation of the river morphology (variable flow channels and sandbank configurations in the river bed). Even the application of sound engineering design practice cannot prevent all sedimentation problems of such smaller intakes for all flow regimes.

In the case of water intakes on rivers which are prone to sedimentation problems in South Africa, there is a need for the removal of sediment from the intakes to ensure continuous water supply from these intakes and to protect the pumps and purification works against damage and sediment clogging, respectively.

With sediment problems being experienced in cases of poorly designed intake structures, temporary emergency intakes as well as intakes operated by farmers, it was considered necessary to launch this research project with the main objective to contribute towards the alleviation of sedimentation problems experienced by intakes on South African rivers and thus improve the assurance of water supplies, as well as to protect intake pumps and purification works against damage and sediment clogging, respectively.

Work which was carried out successfully on the South African coastline effecting the small scale removal of sediment by means of mobile jet type dredge pumps at small craft harbours and

[1]" Smaller intakes" refer to intakes which do not warrant expensive civil works due to financial constraints such as in the case of small local authorities and riparian farmers.

at the Koeberg Nuclear Power Station Cooling Water Intake, prompted the employment/customisation of the jet type dredge pump on rivers.

The objective of this research project was therefore to develop a reliable, simple to operate and low maintenance jet type dredge pump sediment removal system for application in the following two main water intake cases on rivers:

- A permanently installed sediment removal system which is dedicated to a single intake installation.

- A mobile sediment removal system mounted on a trailer which would allow it to be employed at different sites where the need arose.

Results and Conclusions

A national survey of intakes on rivers which experience sedimentation problems revealed the following:

- There is a need for the effective removal of sediment at a relatively large number of river intakes. The smaller intakes on smaller rivers are more prone to sedimentation.

- Sediment entrainment at pump intakes causes excessive abrasion to pumps with consequent high operating costs and undesired interruption in water supply.

- Both minor and major floods cause blockage or disruption of water intakes on smaller rivers.

- Sedimentation problems in some problem cases could be limited by structurally modifying intake works towards more effective designs with due regard to local hydraulic and sediment dynamics/morphology. However, it is considered that even in cases of well designed intakes, some degree of sedimentation is bound to occur. In such cases an effective sediment removal system would serve to control localised sedimentation at the intake.

Based on the above outcome of the survey it was decided to design and assemble a fixed system (dedicated to one intake installation) as well as a mobile (trailer mounted) jet type dredge pump system both of which could be used as experimental units on existing problem cases with the object to evaluate their performances and appropriateness in alleviating the sedimentation problems being experienced.

The fixed experimental unit was designed to be used at one of the problem cases (Sand River intake) where a tap-off from the intake's raw water discharge pipe was used to drive the jet pump system. The 2001 capital cost of this fixed unit was approximately R30 000.

The mobile experimental unit was designed as a self-contained diesel engine driven unit including pipes and accessories to be able to operate at any remote location. The 2001 capital cost of the mobile trailer unit was approximately R160 000. Both the fixed and mobile units had a pumping capacity of approximately 15 m^3 per hour of sand (measured in bulk).

The Department of Water Affairs and Forestry (DWAF) significantly contributed to the investigation by initiating a 12 month contract with a contractor to operate the fixed and mobile experimental units on sediment prone intakes on rivers in Mpumalanga and the Northern Province.

Both the fixed and mobile units were operated successfully during the 12 month evaluation period. Approximately 80 cleaning operations were performed during this period with the mobile unit maintaining approximately 8 sites.

The operating cost (2001) of the mobile unit (including labour, fuel transport and maintenance of the unit) was approximately R3 000 per day in cases where divers were not required and approximately R6 000 per day in cases where divers were required.

One or two days were required to complete a cleaning operation per intake site.

These sediment removal costs are to be compared with the costs at a typical intake to replace or repair a pump which has been damaged by excessive sedimentation (2001):

Capital cost of one raw water intake pump:	R180 000 to R200 000
Repair cost of one raw water intake pump damaged by sand intake:	R60 000 to R70 000
Time taken for repair (causing interruption in water supply):	approximately 2 months

The fixed experimental unit (installed at the Sand River intake) was successful in creating a crater at the raw water pumps intakes. Since the fixed unit used only about 15% of the raw water pump station's discharge and only intermittently when the removal of sediment was required, the operating cost of the fixed system was minimal. Because the main channel of the Sand River at the intake, shifted during both minor and major floods, the crater created by the fixed unit was frequently cut off from the main river channel. The mobile unit was then employed successfully to dredge a connecting channel between the crater and the main river channel to ensure continuous water supply to the intake. [Although not attempted in this study it is considered that at the Sand river intake, two or three additional permanently installed jet pumps between the crater at the intake pipes and the main river channel could maintain a connecting channel to ensure continuous water supply to the intake.]

Although more tests work on sediment removal during the 12 month evaluation period were performed with the mobile unit (mainly due to the large number of existing sediment prone water intake structures), it is considered that the more appropriate application of the jet pump is in a permanently installed fixed mode (this mode does not require divers to operate the jet pump). This implies that the jet pump(s) are dedicated i.e. can be switched on whenever required to prevent sediment ingress and consequent damage to the water abstraction pumps at a river intake.

Based on the performance results obtained during the twelve month evaluation period of the fixed and mobile experimental units it was concluded that the main objectives of the research project were successfully achieved.

The experience of DWAF with the experimental mobile and fixed jet pump systems during the 12 month evaluation period of this research project was sufficiently positive for them to decide to implement a further 2 years contract for the removal of sediment from existing sediment prone intakes in Mpumalanga and Northern Province. During 2002 DWAF also incorporated a permanently installed jet pump system in their design of a new water intake structure at Hoxani on the Sabie River.

Based on the successful conclusion of the investigation it is considered that the project has contributed towards the alleviation of sediment problems at water intake structures on rivers.

Since the capital and operation costs of a permanently (dedicated) jet-type pump system (which is considered the most appropriate method of application) is significantly less than that of a mobile system, it implies that a fixed system will have a larger cost benefit than a mobile system. The capability of a jet-type pump system (either fixed or mobile) to clear an intake from sand has the additional, perhaps more important, benefit of maintaining an intake in an operational condition and therefore ensuring continuous water supply. This benefit is, however difficult to quantify.

It is considered that a large proportion of intakes on rivers with sedimentation problems could be effectively serviced by jet type dredge systems with the same capacity as that of the experimental units used in this investigation (details of which are presented in this report).

It should however be stated that, specifically in cases of fixed jet type dredge systems, custom design is advisable to ensure effective/optimal performance.

Recommendations

As jet pumps could also be used on cohesive sediments it is recommended that further research be performed on the jet type pump's disintegration nozzle configuration to improve its performance in cohesive (not free flowing) sediments such as clay/silt mixtures.

The investigation, besides revealing a need for a sediment removal system, also revealed the need for guidelines on the effective design of intake structures on rivers. It is recommended that consideration be given to transfer the relevant technology in both the above fields to those who are involved in the abstraction of water from sediment laden rivers. The technology transfer could be accomplished by means of workshops or courses.

Legal Issues

In all cases of sediment removal from and discharge back into rivers, all relevant legislation must be taken into consideration. The first step towards fulfilling the Department of Environmental and Tourism's legally prescribed Environmental Impact Assessment (EIA) procedure, would be to approach DWAF for a permit to allow the planned operations. Based on the degree of environmental sensitivity of each case, DWAF would be able to indicate if an environmental impact assessment is required before a permit can be issued.

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AN INVESTIGATION INTO THE REMOVAL OF SEDIMENTS FROM WATER INTAKES ON RIVERS BY MEANS OF JET-TYPE DREDGE PUMPS

1. INTRODUCTION

The problem of sedimentation at water intakes on larger rivers can largely be eliminated or minimised by appropriate design of the civil structures around the intakes. This needs to be done with due consideration of the local morphological and hydraulic conditions.

Well established sound engineering practices (a detailed background of which is presented in Chapter 3) have been developed to ensure sound engineering design of water intakes on rivers. In spite of available sound engineering practices and because of the fact that each intake normally has unique, complex flow characteristics, it is generally advisable to verify each design of an intake in a laboratory by means of a hydraulic model, provided the size of the intake project warrants the cost of a model study.

Sedimentation problems at intakes are relatively common in South Africa especially, in the case of smaller intakes on smaller sediment laden rivers. An example of such a case is presented in Figure 1.1 below. A main cause of the problems is the highly variable flow regime of such rivers (flow rates varying between very low and very high (flash floods) during a season). The consequence of a variable flow regime is significant variation of the river morphology (variable flow channels and sand bank configuration in the river bed). Even the application of sound engineering design practice cannot always overcome all sedimentation problems of such smaller intakes for all flow regimes.

Figure 1.1: Sand River water intake structure and pumphouse with suction pipelines on riverbank. Extensive sandbanks in the river course are visible in the background.

In the case of unsophisticated smaller intakes on smaller rivers which are prone to sedimentation problems in South Africa there is a need for the removal of sediment from the intakes to ensure continuous water supply via these intakes and to protect the pumps and purification works against damage and sediment clogging, respectively.

Other cases where the need arises for sediment removal from river intakes are:
- Emergency intakes
- Small scale riparian intakes such as pumping intakes from rivers used by farmers

During times of drought when existing river intakes fail due to flow levels that are too low, emergency intakes have to be implemented to supplement water supply. The emergency intakes usually do not warrant expensive civil works, are usually not located at ideal locations and are often subject to sedimentation problems. There is also a need for effective sediment removal in the case of temporary emergency intakes e.g. where floods have caused damage to pump stations or pipelines.

Small scale extraction of water from rivers by riparian farmers generally does not warrant expensive civil works to ensure reliable water extraction. The consequence is that farmers who have to extract water from sediment laden rivers, often have to deal with pumping intakes swamped by sediment (e.g. after a flood). In such cases there also exists the need for the removal of sediment.

Having identified existing sediment problems at many river intakes, it was considered necessary to launch a research project with the main objective to help overcome such problems.

Recent work which had been carried out successfully on the South African coastline on the small scale hydraulic removal of sediment by means of mobile jet pump type systems at small craft harbours (Prestedge and Bosman, 1994), as well as at the Koeberg Nuclear Power Station Cooling Water intake, prompted an investigation into the possible employment/ customisation of the jet type dredge pump to solve river sedimentation problems.

Mechanical removal of sediment was not considered in this study since it is common knowledge that hydraulic removal and transport of sediment is generally less costly than by mechanical means.

The composition of this report is as follows:

This report defines the objectives of the study in Chapter 2. In Chapter 3.1 a detailed background is presented on causes of sedimentation at river intakes and principles of effective design of intake structures to manage sedimentation at intakes. The successful application of jet type dredge pumps in the specific field of coastal engineering (as obtained from literature) is also covered in Chapter 3.2.

The methodology used in the investigation is presented in Chapter 4.

Sedimentation problems at a number of intakes on rivers are described in Chapter 5. Based on the problem cases which had been encountered, two test systems (systems utilising the jet type dredge pump) were designed and assembled, the detail of which is presented in Chapter 6. The evaluation results of the test systems which were employed in the field on problem cases are presented in Chapter 7.

Environmental issues in dealing with the disposal of removed sediment are addressed in Chapter 8.

In Chapters 9 and 10 the report is concluded with discussions on the outcome of the investigation, final conclusions, general guidelines on the application of jet type dredge pumps at river intakes and recommendations for further research.

For the purpose of supplementary information to the investigation the results of sediment particle size distribution of cases included in the investigation as well as basic principles of transport of sediment in pipes are presented in Appendix A.

The authors of this report are listed in the front of this report with particular inputs of Prof. A Rooseboom in Chaper 3.1 and Prof. P T Slatter in Appendix A.

2. AIM OF THE PROJECT

With sediment problems being experienced at a significant number of South African water intakes on rivers and the identified potential of jet type dredge pumps to contribute towards the solution of the problem of sediment prone intakes, the main aim of this project was to develop a reliable, simple to operate as well as low maintenance jet type dredge pump sediment removal system which is suitable for application in the following two main river intake cases:

i) Permanently installed (fixed) sediment removal system where accumulating sediment is to be removed from either inside or outside the pumping station intake.

ii) Mobile sediment removal system where sediment needs to be removed from either inside or outside a pump intake. The mobile unit should be transportable (preferably on a trailer) enabling it to serve where and when required both at existing and emergency intakes.

The aim of the project was to evaluate in principle the applicability of the jet-type dredge pump at water intakes on rivers and if found applicable, to adapt it where necessary towards the effective removal of sediments from water intakes on rivers.

The development of a design manual for the application of a jet type dredge pump did not form part of this investigation.

3. BACKGROUND INFORMATION

Considerable knowledge and engineering guidelines on the appropriate design of river intakes (with reference to morphological and hydraulic aspects) exist. A detailed background of this knowledge is presented in Section 3.1 below.

The successful application of the jet type dredge pump in the specific field of coastal engineering is presented as further background to this study in Section 3.2.

3.1 CAUSES OF SEDIMENT-RELATED PROBLEMS AT WATER ABSTRACTION WORKS ON SEDIMENT-LADEN RIVERS AND PRINCIPLES OF EFFECTIVE DESIGNS

3.1.1 Introduction

In order to design and operate abstraction works, flow and sediment transportation patterns in rivers need to be understood. The following overview of Southern African experience serves to identify the causes of typical existing problems as well as the principles of effective designs. This chapter contains material which has been extracted from WRC Report No 691/2/02 titled "The Extraction of Water from Sediment-laden Streams in Southern Africa". The latter report deals with rivers that carry coarse sediments as well as those that carry fine sediments. This chapter refers only to finer sediments (sand, silts, clays) which form the bulk of the sediments being carried in situations where jet type dredge pumps find application.

3.1.2 Problem Areas

In those Southern African rivers that carry mainly sands, silts and clays, a large proportion of the annual loads will be carried during flood events. Suspended sediment concentrations then tend to vary only slightly across flow cross-sections. The ease with which the relatively small suspended sediment particles become accelerated causes them to be dispersed from flow zones where flow capacities are high into zones where flow capacities are low.

Conditions that should be ideal at pump intakes i.e. low velocities and especially low vorticity thus tend to collect suspended particles from passing streams. Even when water is not being pumped, sediments can be fed continuously into a pump's wet well through a connecting opening from areas of high vorticity. Wet wells and other spaces, containing slow moving water, which are connected to sediment-laden streams, tend to become filled with sediments, leading to higher sediment concentrations being pumped than those present in the flowing river.

Pump houses with small outside openings have been found to be more than 80% filled with sediments after having been inundated during a single flood event. Relatively small rapid-flowing streams have the ability to transfer gravel and even cobbles in a similar fashion into slow-flowing zones.

Other causes of sediment related problems which have been encountered at water extraction works include:

i) Changes with time in river channel positions and in cross-sectional shapes.

ii) Sediment build-up due to flow retardation caused by dams or other structures further downstream.

iii) Sediment build-up, particularly in deep river pools, due to flood attenuation caused by dams upstream.

iv) Sediment build-up caused by increased sediment loads.

v) Bank encroachment, particularly during periods without the major floods which would normally have re-established the full channel width.

vi) Increased sediment and flood levels caused by vegetation becoming established on sedimentation deposits in the delta regions of reservoirs, as well as (far) downstream of dams. The growth is often stimulated by nutrient-rich run-off from irrigated areas, especially if such run-off occurs during periods when the rivers would naturally have run dry. Alien vegetation tends to cause increased flooding even in the absence of dams.

vii) Damage to pumps caused by high sediment concentrations and/or large particle sizes. The damage is often increased as a result of high entrance vorticity levels, which lead to cavitation.

viii) Differing flow patterns during high and low flows.

ix) Sediment deposition in unexpected areas, e.g. on the outsides of sharp bends in rivers. This is found in steep, rocky rivers where hydraulic jumps are formed within the upstream legs of bends. Sediments carried by the fast oncoming flows are thus deposited in the backwater behind the hydraulic jumps.

x) Slumping of deposits of (finer) sediments causing blocking of intakes when water levels are drawn down rapidly.

3.1.3 Sediment Transport and Deposition Patterns in Southern African Rivers

3.1.3.1 Introduction

The majority of water extraction works in Southern Africa are found on rivers that transport mainly fine sediments, including clays, silts and sands. The remaining works are found mostly on steep rivers that carry coarse sediments that may include gravel, cobbles and boulders, in addition to fine sediments.

3.1.3.2 Sediment concentrations

Where sediment loads consist mainly of fine sediments, the loads are normally found to be availability limited. On the other hand, the loads of coarse sediments are generally determined by the carrying capacities of the streams.

The main characteristic of loads of fine sediments, is their variability. Long term records are therefore required in order to obtain accurate estimates of average annual loads.

In the design of water extraction works, information may not only be required on the average long term sediment load, but also on maximum suspended sediment concentrations that need to be catered for. Most of the original South African records of measured sediment concentrations are no longer available.

From previous experience, it can be recommended that the following suspended sediment concentrations may be used for design purposes in cases where no records exist and where the size of the project does not warrant a sampling programme:

2% by mass (20 000 mg/l) – this value is likely to be exceeded, particularly during flood events.

4% by mass (40 000 mg/l) – this value is likely to be exceeded from time to time only after exceptionally heavy rainfall storms across the catchment.

6% by mass (60 000 mg/l) – this value is exceeded very rarely and only on rivers that carry heavy sediment loads.

As extreme rainfall events tend to occur over limited areas, the river discharges that carry the highest concentrations may be small. One of the highest concentrations on record of 6.5% by mass (65 000 mg/l) was measured on the Caledon River when the discharge was only some 80 m^3/s .

High variability is not only a characteristic of suspended sediment concentrations but also of daily and even annual loads.
As cumbersome and expensive sampling programmes over long periods (5-7 years) are required to determine suspended sediment loads accurately, existing load data is extrapolated by means of sediment yield maps in areas where loads are availability limited.

3.1.3.3 Sediment yields

The data base which has been built up on sediment yields (based mainly on reservoir re-surveys) for different catchments, has been used to develop the most recent sediment yield map of Southern Africa (Rooseboom et al, 1992). This map may be used to estimate average sediment loads where no sediment load data are available.

3.1.3.4 Sediment accumulation in reservoirs

In many cases weirs form essential components of river extraction works. Not only do weirs provide the necessary heads required to flush and scour sediments from intake areas, they also serve to direct low flows towards intakes. However, the pools behind weirs tend to become filled with sediments.

Unless large gates (with a total capacity in the order of the 5 year peak flood discharge) are provided, a large proportion of the original storage capacity behind a weir is likely to be lost due to sedimentation. The average water storage depths behind weirs may drop to 300mm or even less.

The shapes of sediment deposits behind weirs need to be analysed not only in terms of the threat that they may pose to the extraction works, but also in terms of build-up upstream of reservoirs. Serious problems have arisen due to under-estimation of the extent of sediment build-up upstream of the actual reservoir basins and large additional areas have had to be expropriated. In unfavourable situations, sediment build-up could occur over a considerable distance upstream of the original full supply line.

Simplistic empirical rules on sediment deposit shapes as those quoted in ICOLD (1989) have proven to be very unreliable, particularly in the case of small reservoirs.

Prediction of further equilibrium profiles needs to be based on:

i) determining the equilibrium sediment level directly behind the weir. This is done by determining the level at which the critical shear velocity of the sediments is exceeded.

ii) step-wise analysis of the equilibrium sediment profile in an upstream direction. It has been found (Rooseboom and Van Vuuren, 1988) that as the sediment profile approaches equilibrium, the shear velocity $\sqrt{gDs}$ approaches a constant value for a specific flood discharge through the reservoir.

where :

g	=	acceleration due to gravity
D	=	flow depths (hydraulic radius)
s	=	energy gradient

iii) More sophisticated routing calculation procedures have become available (Basson and Rooseboom, 1997). Parameters that define critical or equilibrium conditions should be determined from comparable existing deposits, particularly in the case of cohesive sediments.

iv) Vegetation that becomes established on sediment deposits can increase flow resistance and can complicate matters by inducing an increased build-up of sediments as well as by increasing the resistance to scour of the deposits.

3.1.4 Water Extraction from Rivers that Carry Heavy Loads of Fine Suspended Sediments

3.1.4.1 Introduction

The two main options that are available for the extraction of water consist of:

i) Installing pumps where there is sufficient natural water depth available and it is not necessary to erect a control structure across the river.

ii) Creating controlled water and sediment discharge conditions by means of weirs and auxiliary works, which limit the ingress of sediments into pumps or canals.

Given their capacity to extract water from near-empty sand-bedded rivers, jet type dredge pumps provide a further alternative, particularly for short-term emergency works.

As low flow conditions are common to most Southern African rivers and natural stable pools are often not available, weirs form essential components of many extraction works.

3.1.4.2 Weir-less installations

This category includes pumps that are installed in or alongside natural pools in rivers, often on the outsides of bends in the rivers. Such installations are very common in smaller scale irrigation schemes and have also been used for relatively large temporary pumping projects. They are best suited to stable river channel configurations and limited variations in water levels and are generally too vulnerable to be used in large scale permanent installations. A notable exception is found in the form of pumps that are mounted on trolleys which can be moved on rails up and down sloped banks as river levels rise and fall. Such installations have been used successfully in cases where river levels change slowly and where ample warning time is available with regard to imminent changes in water levels, e.g. along the lower Orange River. These sloping installations have an advantage above wet-well tower installations because they will not extract higher concentrations of sediments than are present in the flowing water.

Pumps mounted on floats to accommodate changes in water levels have not found wide application in Southern Africa, mainly due to the high variability in flow levels as well as problems caused by floating debris.

Pumps have been mounted on the upstream ends as well as the downstream ends of bridge piers. Where debris is a problem, it is better to have a pump at the downstream end of a pier.

The success rate of water extraction towers that were not constructed in conjunction with weirs or dams has been low on Southern African rivers. The high vorticity levels which are typically generated at the inlets of isolated towers not only pose a cavitation threat to pumps but also lead to abnormally high rates of sediment ingress as was explained before. Based on serious problems experienced at a number of massively large towers, it is considered important to sound a warning against their use unless adequate water depths and low enough vorticity levels can be guaranteed. Such towers work best where they are built in conjunction with weirs in which case they form integrated components of the weir lay-outs.

3.1.4.3 Weir installations : a basic lay-out

With many of the most suitable sites for storage dams on rivers having been utilised, an increasing number of smaller weirs are being constructed for extracting water from sediment laden rivers, often to provide water to off-channel storage facilities. From a sedimentation point of view it is highly advantageous to have off-channel storage instead of storage on the supplying river. As even relatively small storage reservoirs trap most incoming sediments, storage losses due to sedimentation tend to be much less in the case of off-channel storage. This is due to the fact that sediment concentrations tend to reach high peaks over short periods. If water is thus extracted from a river stream at a near constant rate, the proportion of the total sediment load which is extracted tends to be much lower than the proportion of the total water discharge which is being extracted.

When the collection of information on weir installations that have been successful was started, it was anticipated that a number of different lay-outs would be identified. An “ideal” basic lay-out can however be defined, which can be adapted or simplified to suit specific conditions.

The lay-out as shown in Figure 3.1, is for extraction in a downstream direction. For sideways extraction, the components need to be in the direction of extraction.

Without a pump station some of the components will fall away where water is being fed into a long distance tunnel or canal.

The basic lay-out (Figure 3.1) may contain:

Weir	A
Spillway	B
Open intake	C
Screen intake	D
Scour gates	E
Scour chamber	F
Collection channel	G
Control gate(s)	H
Transition channel(s) or tunnel(s)	I
Vortex suppressor	J
Settling basin	K
Pumps	L
Low notch weir	M
Groyne	N

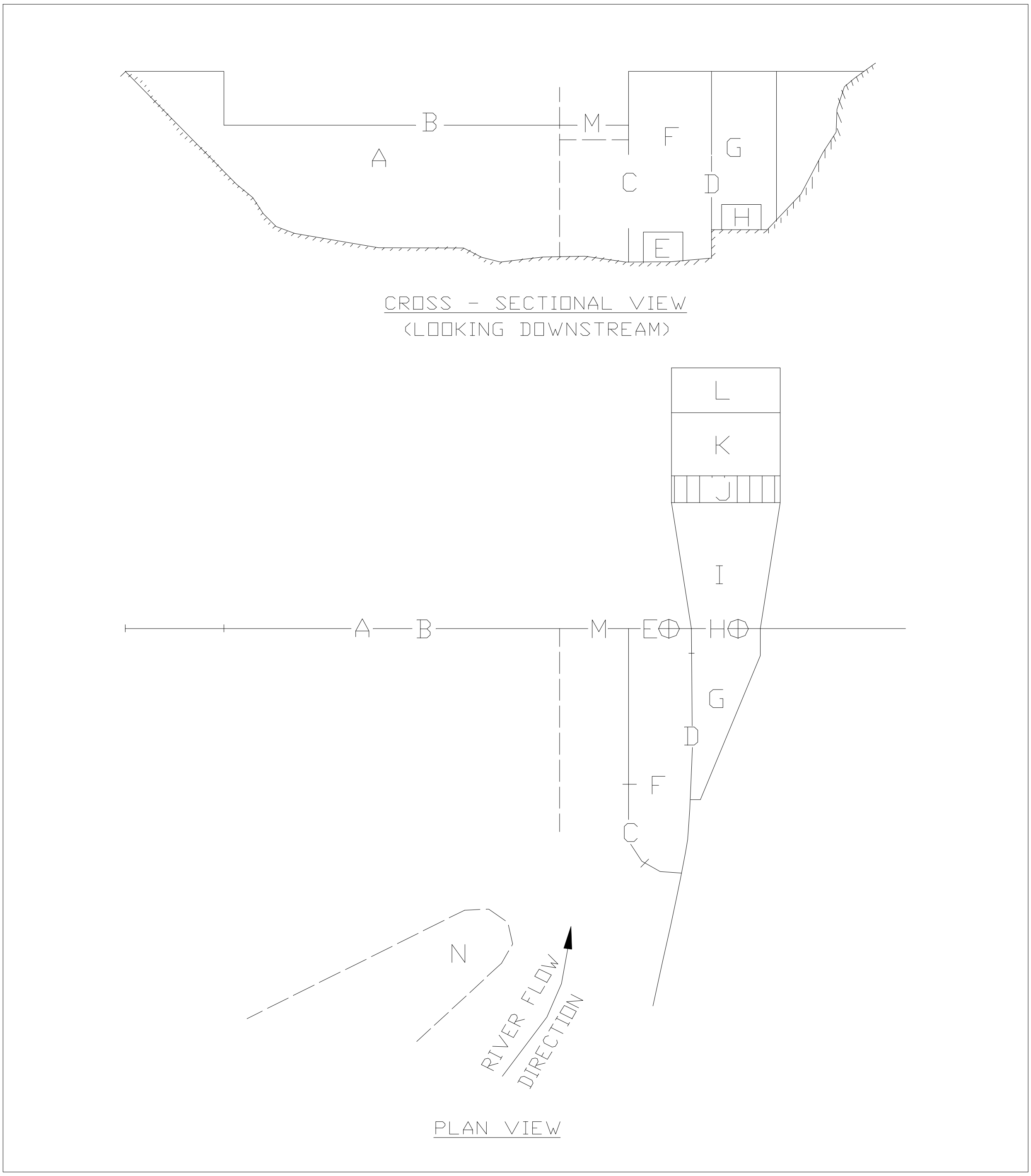

Figure 3.1: Basic lay-out of a pumping extraction works at a weir

In designing the different components, the following should be borne in mind:

A Weir

It is generally accepted that the best position for the weir is somewhat downstream of the halfway mark in a bend of a river. This position is chosen in order to make maximum use of the scour action along the outside of a bend. This action however, tends to be dampened by the presence of the weir, as the spiral flow components that work downwards along the outside bank are weakened when flow velocities are caused to decrease.

It is possible on the other hand to induce local scour by increasing velocities and by decreasing flow radii (in plan) by means of groynes or other structures. It has been found possible to create scouring conditions even along the insides of bends by means of such structures.
Not all bends are suitable for the construction of weirs for extraction purposes. The outsides of bends on steep rocky rivers for instance can be subject to heavy sediment deposition during floods. On solid foundations weirs tend to be concrete or rollcrete gravity structures. On poor, erodible foundations Ambursen-type abutment and slab weirs have been successfully employed for extraction works.

B Spillway

The spillway must obviously have sufficient discharge capacity to limit flood damage. An important aspect in this type of spillway design is that water levels downstream of the scour gates need to be low enough to make scouring possible. It is sometimes necessary to enforce a hydraulic jump some distance downstream of the weir for this purpose.

C Open intake

An important function of the wall, which contains the open intake, is to keep floating debris out. For this reason the upper level of the intake opening should be low enough to prevent floating objects from being sucked through. [Flow velocities through the opening must therefore also be low enough through the intake.] The bottom of the opening on the other hand needs to be high enough to create sufficient gradient for flushing sediments from the scour basin as well as to create sufficient space for temporary accumulation of sediments.

D Screen intake

The screen serves to stop suspended debris. Screen opening sizes therefore depend on the sizes of objects which can be allowed to be passed downstream. As screens tend to become blocked by relatively small masses of debris their openings need to be as large as possible. It is generally more practical to settle suspended debris (as opposed to floating debris) out in a settling basin rather than to trap it with screens. The upper edge of a screen should also be below the water surface in order to limit the entanglement of floating debris (Refer Rooseboom (2002) for more detail).

E Scour gate(s)

Scour gates need to be positioned low enough to keep sediment levels down. At the same time they cannot be so low as to not be able to discharge freely when required.

F Scour chamber

The dimensions and shape of the scour chamber are of major importance. Apart from its function to collect sediments that settle out temporarily, the outer wall serves an important function by inducing scour along its outside perimeter. If properly shaped, the chamber may be considered to be equivalent to half a bridge pier with the capacity to induce deep scour around it, particularly at the upstream end. Beneficial use could be made of pier scour mechanisms at extraction works (pers. com. Leon Fürstenburg of Knight Piesold).

Given that the scour depth for a pier (and also half a pier) is directly proportional to the pier width, it is beneficial to have the scour chamber as wide as possible from the point of view of limiting sediment build-up around the intake area during floods. However, the high vorticity levels which are typically generated in scour chambers are unfavourable from the point of view of pumps, and it is thus not advisable to pump directly from a scour chamber . The outer wall of the scour chamber should be streamlined and its downstream section should run parallel to the flow direction (in plan) in order to be able to pass floating debris downstream over the spillway crest, particularly where a low notch is provided.

G Collection channel

In order to limit sediment accumulation in the collection channel, velocities here should be relatively high and constant. For this reason the channel floor is raised and it widens in a downstream direction.

H Control gate(s)

Due to their high costs, the sizes of gates are kept as small as possible. This leads to high downstream velocities and excess energy has to be dissipated. Transitions may also be required to develop smooth uniform flow prior to the water reaching a settling basin or pump intakes.

J Vortex suppressor

Where vorticity needs to be dampened prior to water reaching pump intakes or settling basins a vortex suppressor needs to be installed in order to create smooth uniform flow conditions (refer Rooseboom (2002) for more detail).

Stacked pipe walls consisting of asbestos cement pipes have proven to be very effective for this purpose. (A pipe length to inside diameter ratio of 10 may be recommended for this purpose).

K Settling basin

Where it is necessary to settle out particles of given sizes settling basins are required. Bouvard (1992), Raudkivi (1993) and Mehtotra (1997) provide valuable information concerning the design of settling basins.

L Pumps

The basic layout can be used in conjunction with either a wet well or dry well installation. The components associated with the pumps can be integrated into a pump tower adjoining the weir.

M Low notch weir

A low notch weir can serve two purposes. Firstly it helps to maintain a low flow channel towards the intake in sediment-filled reservoirs. Secondly it can pass floating debris which accumulates around the intake over the weir. This can be very valuable in cases where large volumes of floating debris such as trash or water hyacinths prove to be a problem.

The efficiency of a low notch weir in passing floating materials can be increased substantially by providing a guide wall, which concentrates flow past the intake wall.

N Groynes

Groynes and other flow directing structures have proven to be very effective in keeping sediment deposit levels low in front of intakes. As most sediment accumulation takes place during floods, such accumulation can be limited if high scouring capacities can be generated around the intake area. This is achieved through groynes which concentrate flows, pushing up velocities and also by increasing the curvature of flow lines (in plan).

It is often not possible to design such structures theoretically as small variations in lay-out can impact significantly on efficiency. Physical model studies are thus required to optimise lay-outs.

3.1.5 Jet Type Dredge Pumps used in conjunction with weirs

Even with the best weir lay-outs, local sediment deposits tend to accumulate in "dead" areas, particularly during floods. Whilst such "dead areas" should be as small as possible, the provision of dredge pumps to help clean out the dead areas after floods as part of the integrated design is to be recommended.

3.2 INFORMATION FROM LITERATURE ON SEDIMENT REMOVAL BY MEANS OF JET-TYPE DREDGE PUMPS IN THE COASTAL ENGINEERING FIELD

Literature on removal of sediment from river intakes where flushing cannot be practised is sparse. Conventional dredging has been utilised in some cases where this is practical.

A novel method of removal of sediment in the marine environment is the employment of a permanently installed jet type dredge pump or series of jet pumps. The Nerang fixed sand bypassing system (Wakefield 1994) operational on the Australian East Coast since the 1980's is a good example of a successful fixed jet-type pump sediment removal system. The Nerang sand bypassing project is presented schematically in Figure 3.2.

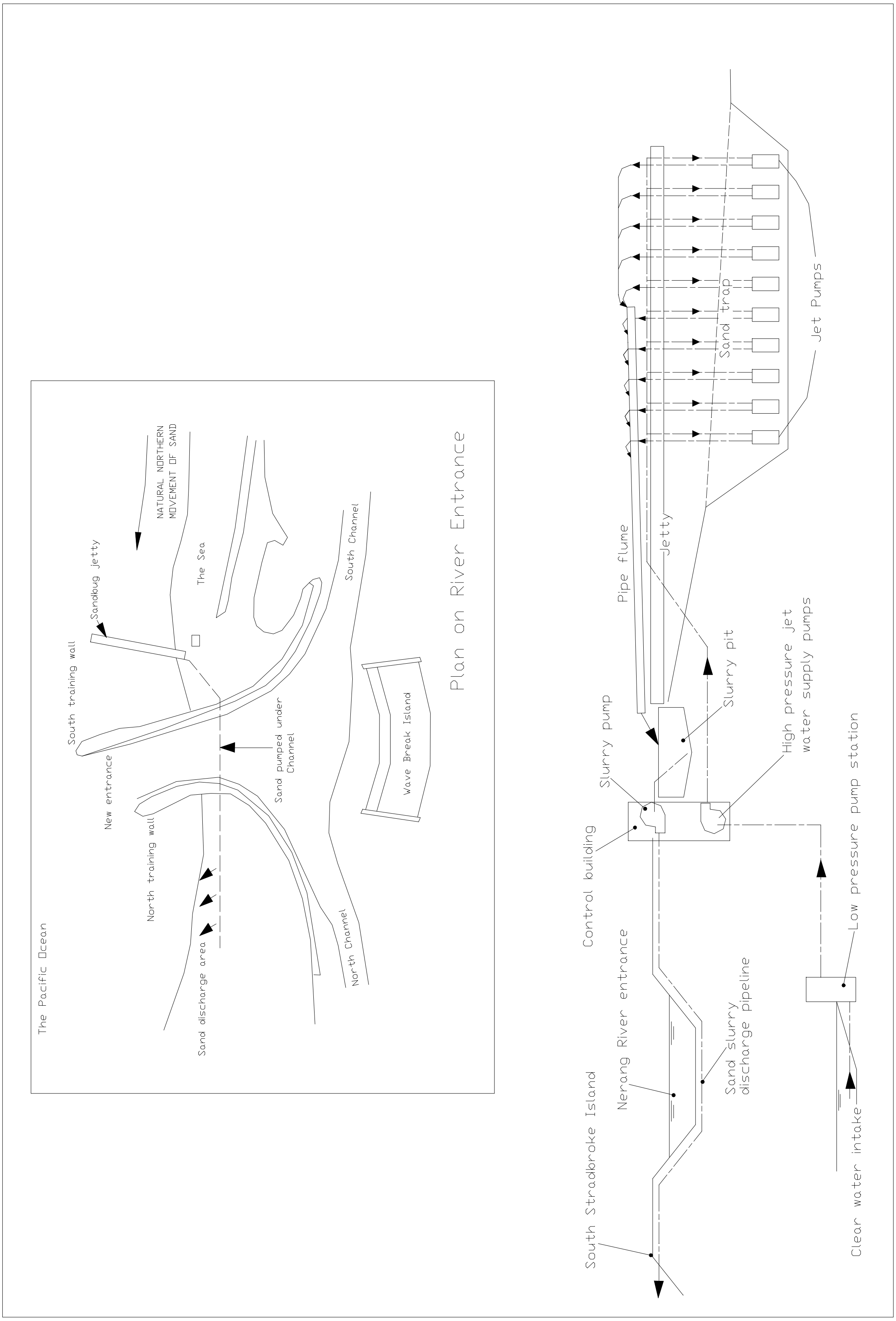

Figure 3.2 Schematic diagram of Nerang fixed sand bypassing system (Wakefield, 1994). Jet pumps mounted on a jetty at the updrift side of the main training wall pump sand via a pipeline underneath the entrance to discharge on the downdrift side.

The principle of jet-type dredge pump operation is shown in Figure 3.3.

The jet type dredge pump is different from other pumps in that it contains no moving parts and is powered by a jet of clear water. The clear water is supplied by a separate pump (usually a centrifugal pump). The basic principle behind the operation of the jet pump is the exchange of momentum within the pump (refer Figure 3.3). Clear water, normally supplied by a centrifugal pump, enters the jet pump through a central jet. Turbulent mixing occurs between the central water jet and a sand-water mixture in the suction chamber. This causes low pressure in the suction chamber which draws a sand-water mixture via the suction duct into the slurry delivery pipe via the mixing chamber and diffuser. Small water jets near the intake end of the suction duct disintegrates the surrounding sediment and enables the sediment to flow towards the suction duct end.

The main advantages of a jet pump dredger versus a centrifugal pump dredger are :

- The suction end of the pump operates at its highest efficiency when it is buried in the sand whereas a centrifugal pump suction end will tend to be clogged under these conditions.

- The jet pump pipe system does not tend to clog since it is driven by clear water. This simplifies the operation of a jet pump dredger and contributes to its reliability.

- With the jet pump suction end buried in the sand, turbidity (which could impact negatively on the environment) is limited.

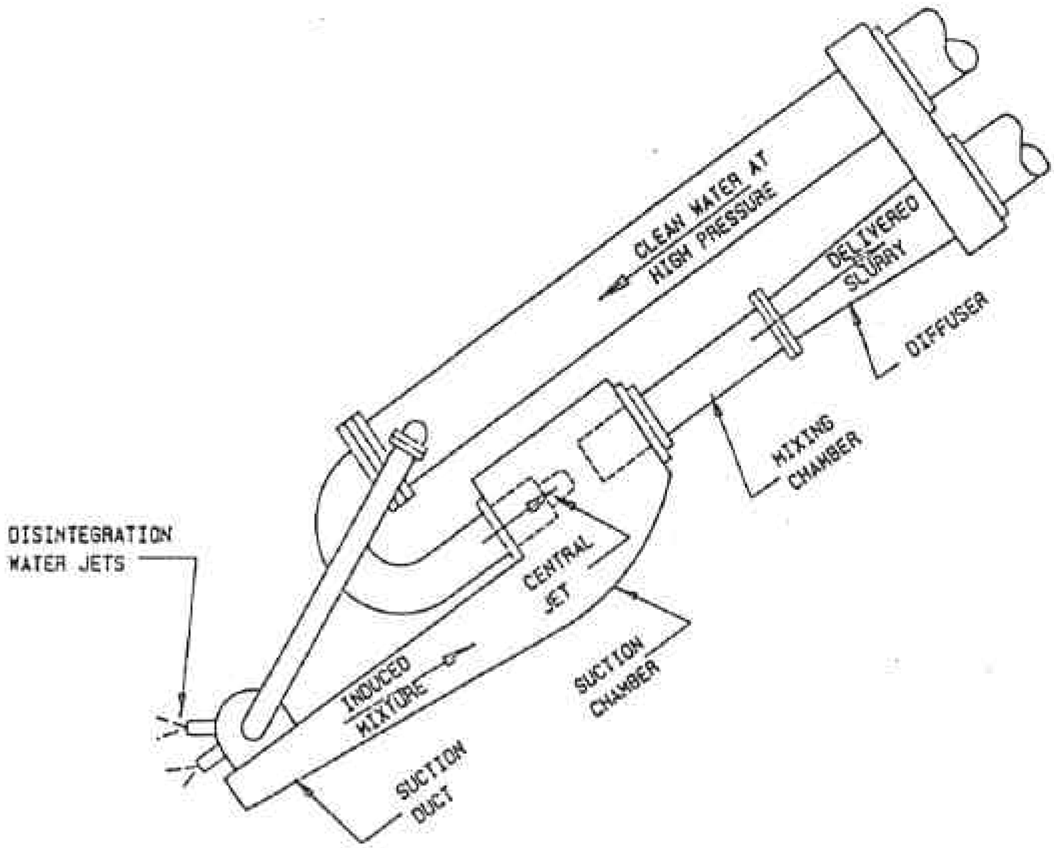

Figure 3.3: Jet pump components (Prestedge and Bosman, 1994). Clean water at high pressure is supplied to the central jet and disintegration jets. Sediment is entrained into the mixing chamber and velocity head is converted to static head in the diffuser to carry slurry further to the discharge point.

The jet type dredge pump can be manufactured from very small capacity e.g. a size that can be handled by one man/diver (with a pumping capacity of about 10 m^3 per hour) to very large capacity. The more common larger size used on a conventional floating dredger usually has a pumping capacity of about 100 m^3 of solids per hour for a discharge distance of about 100 m without the need of a booster pump (longer discharge distances are possible by the addition of a booster pump in the discharge pipeline).

The smaller jet type dredge systems in use in South Africa in the marine environment have a pumping capacity of about 40 m^3 solids (bulk volume) per hour. Such a unit has been utilised for maintenance dredging at the Club Mykonos small craft harbour in Saldanha Bay since 1992 (Prestedge and Bosman, 1994). This unit is presented schematically in Figure 3.4 below.

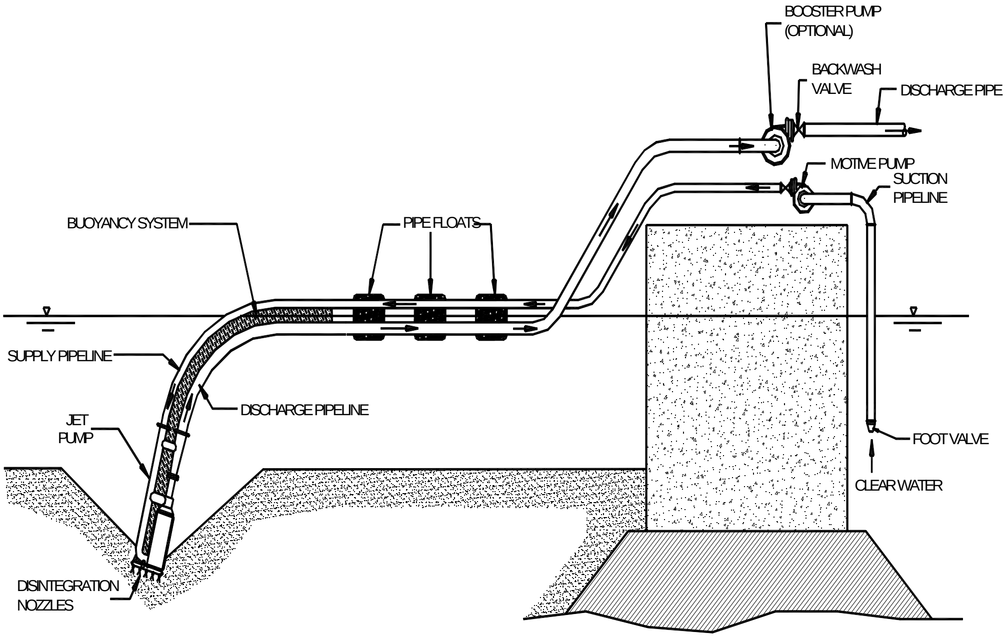

Figure 3.4: Schematic presentation of Mobile Dive Dredger (Prestedge and Bosman, 1994)

4. INVESTIGATION METHODOLOGY

The methodology followed in this study comprised the following steps :

i) Identification of pumping intakes where sedimentation problems are experienced.

ii) Site visits to selected problem cases and collection of relevant information.

iii) Design, cost, procure and assemble a fixed as well as a mobile test plant.

iv) Application (test operation) and evaluation of fixed and mobile test plants at selected problem sites.

The main target of the first and second steps was to define the needs, circumstances and requirements of the sediment removal systems. This was done by means of enquiries, interviews and site visits.

The design of the mobile and fixed test plants was done within budget constraints and with due consideration of the selected problem cases in the Mpumalanga and Northern Province areas (where evaluation tests were planned) in close collaboration with the Department of Water Affairs and Forestry (DWAF).

Evaluation of the test units was also done in close liaison and with substantial assistance from DWAF who appointed an operating contractor for evaluation testing of the pilot plants on problem cases in the Mpumalanga and Northern Province rural areas.

Relevant information including sediment characteristics for problem cases were obtained and existing background information on transport of sediment in pipes were also incorporated as supporting information to this study (Appendix A).

5. PROBLEM CASES AND INFORMATION OBTAINED FROM SITE VISITS TO SELECTED CASES

5.1 TARGET ORGANISATIONS

To identify sedimentation problems and the need of a sediment removal system at existing pumping intakes on rivers, the organisations which operate pumping intakes were first determined. Some of these organisations were then approached by telephone and interviewed. This was then followed up with a site visit kindly organised by the Department of Water Affairs and Forestry (DWAF) to a number of problem cases in Mpumalanga and the Northern Province.

5.1.1 Determination of Target Organisations

DWAF is the main organisation which operates pump stations on a national basis.

The second major category of organisations are Water Boards of which there are about 17 in South Africa (refer to Table 5.1 for a list of Water Boards).

Table 5.1 : List of South African Water Boards

1.	Albany Coast Water Board (Boesmansriviermond)
2.	Bloem Water (Bloemfontein)
3.	Bushbuckridge Water Board (Mafmani/Nelspruit)
4.	Goudveld Water (Bothaville)
5.	Kalahari East Water Board (Upington)
6.	Kalahari West Water Board (Upington)
7.	Karos-Geelkoppen Water Board (Joostepan)
8.	Lepelle Northern Water (Phalaborwa)
9.	Magalies Water (Tehabane - Rustenburg)
10.	Mhlathuze Water (Richards Bay)
11.	Namakwa Water (Nababeep)
12.	North-West Water Supply Authority Board (Mmabatho)
13.	Overberg Water (Heidelberg CP) (Western Cape)
14.	Pelladrift Water Board (Marshalltown)
15.	Rand Water (Johannesburg)
16.	Umgeni Water (Pietermaritzburg)
17.	Umgeni Water Regional Office (Durban)

The third category includes Rural Water Supply Schemes in the previously disadvantaged rural communities. A large number of pumping intakes (forming part of water distribution systems) were constructed during recent years by the private sector (with Government funding via DWAF) for the previously disadvantaged under the so-called BOTT (Build, Operate, Train and Transfer) programme. This was done particularly in the more densely populated rural areas of Mpumalanga and Northern Province. The site visits of pumping intakes on rivers with sediment problems arranged by DWAF were to pumping intakes in this category.

The fifth category includes smaller abstractors such as farmers.

5.2 INFORMATION OBTAINED FROM TARGET ORGANISATIONS

5.2.1 Department of Water Affairs and Forestry

Information was obtained by means of telephone interviews, correspondence and site visits. DWAF also arranged a field trip for the project team to a number of intakes of Rural Water Supply Schemes funded by DWAF for previously disadvantaged communities in the Mpumalanga area. Based on the information obtained by the above means, problems at different sites are described below :

The locations of the intakes which were inspected are shown in Figure 5.1 below.

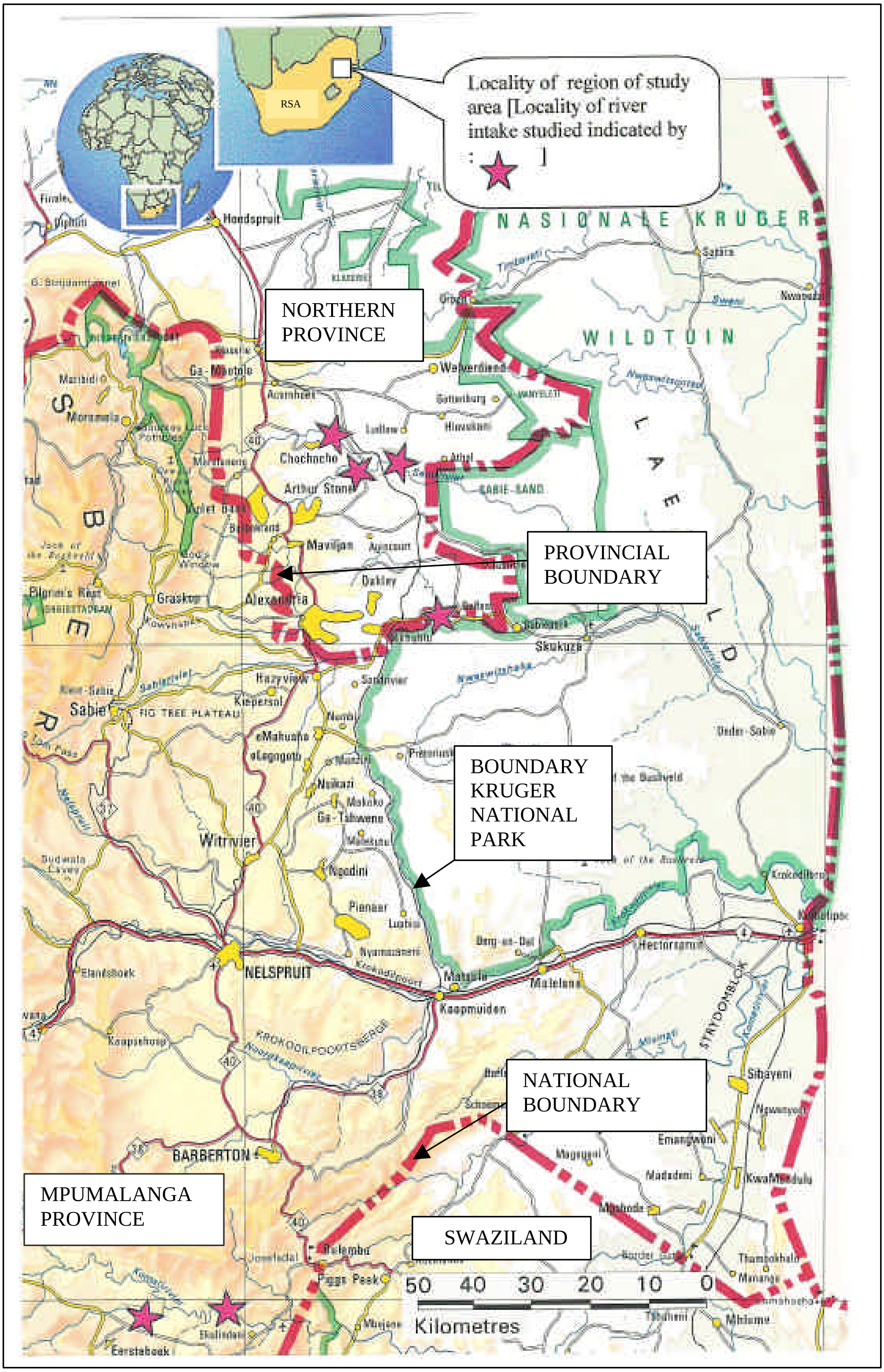

Figure 5.1 : Main study area : The locations of some of the water intakes on rivers which were included in this study are indicated.

i) Kanyamazane/Nsikazi South Intake (near Nelspruit)

The flow rate through this intake is approximately 500 litre/second (35 Ml/day) and it serves a community of approximately 500 000 people. The pump station is equipped with APE vertical multi-stage spindle pumps. The pump sump is connected to the river by a 1.5 m x 1.5 m culvert and opens in a gully on the river bank. During floods the gully and consequently also the intake culvert and pump sump are filled with sand and rock. The intake is then completely blocked (this has occurred twice during a period of 12 months with the most recent occurrence during the February 2000 floods). Mechanical equipment is then used to remove sediment from the gully and conventional sand pumps operated by divers are used to clear the intake culvert and pump sump. During the times of blockages temporary pumps with suction pipes mounted on a float are used to extract water from the river.

The operation of the water supply scheme (including the intake pump station) was, at the time of the visit, in the process of training and transfer (part of the BOTT programme) to the local community.

The sediment particle sizes in the river vary significantly. Due to rapid flow in the river during floods up to 100 kg stones are moved. The median sand grain size is in the order of 450 micron.

ii) Eerste Hoek Intake (near Badplaas)

Figure 5.2 shows the intake on the river bank of a tributary of the Komati River.

Figure 5.2 : The Eerste Hoek intake on the Komati River

The pump station is provided with two multi stage vertical spindle pumps mounted at a slope to enable adjustment of the suction ends of the pumps. Adjustment is however cumbersome because it requires the insertion/removal of sections of pipes and drive shafts. During minor and major floods sand deposits at the location of the intake to such an extent that the suction ends of the pumps are covered by sand. The result is that the pumps entrain sand (or are completely blocked) with the consequence that the mechanical parts of the pumps are seriously abraded. Maintenance cost is therefore high.

The pumping rate is approximately 100 l/s at a head of 12 m. The operation of the water supply scheme is in the process of training-and-transfer to the local community.

The sediments in the river are coarse (approximate median grain size of 400 micron - refer to Figure A1 in Appendix A.)

iii) Komati Transfer Intake (near Badplaas)

This intake is located on a tributary of the Komati River. A floating type intake system moored to three anchors on the river banks is used. Submersible pumps are mounted on the float system. Water is pumped by the submersible intake pumps via rubber hoses to the pump station on the river bank from where water is pumped further to the purification works. During the February 2000 floods the float installation was washed away. The submersible pumps presently operate in the shallow water on the sandy river bank. This leads to entrainment of sand and frequent overheating of the pumps when the pumps are not fully submersed to enable cooling.

The pumping rate of this pump station is 50 l/s.

The intake is located in a remote location far from developed areas and is served by a poor quality road. The sediments in the river are coarse (median grain size of approximately 250 micron - refer Figure A1 in Appendix A).

iv) Hoxani Intake on the Sabie River (near Hazyview)

Figure 5.3 below presents the Hoxani intake. The pump intake is located on the Sabie River which is normally low flowing outside of the rainy season but is characterised by frequent flooding during the rainy season. At the intake location the river has a rocky bed but with significant sediment loads passing during minor and major floods.

Figure 5.3 : Hoxani Intake on the Sabie River

The intake is provided with four submersible Flygt pumps which are located in a concrete sump near the centre of the river. The pump sump is frequently sanded up after rains with increases in river flow. The capital cost (2002) of each pump is about R200 000 and repair costs of impellors and bearings due to sand abrasion amount to about R100 000 per pump.

The median grain size of the sediments is approximately 600 micron with approximately 2% silt content (refer Figure A1 in Appendix A).

v) Sabie River Intake (Nzikazi North near Hazyview)

Figure 5.4 below shows the Sabie River Intake which is located on the opposite bank of the Sabie River where the Hoxani Intake is located.

Figure 5.4 : Sabie River Intake (The intake is in the right foreground and the pump house is in the left background).

The pump station is provided with multi stage vertical spindle pumps located in a pump sump. Water flows from the river to the pump sump via a 600 mm diameter pipe. The river end of the 600 mm pipe is provided with an intake structure in the river bank (refer Figure 5.4). The intake is frequently choked by sand after both minor and major floods and consequent increases in river flow. When this occurs the sand is entrained via the intake pipe into the pump sump and consequently into the pumps. This causes severe wear to the pumps which results in high maintenance costs and breakdowns.

The removal of sand from the intake pipe and pump sump is a costly operation. At the time of the visit a contractor was employed to remove the sand. A conventional centrifugal pump as well as an annular-jet type pump (used in the mining industry) was used to remove the sand from the sump. The operation was cumbersome because of the flat floor of the pump sump room. Divers and a large number of labourers were required in the operation. A conically shaped sloping floor (to enable sediment to gravitate to a central location from where sand could be pumped) would have eased the operation.

The jet pump used during the site visit operated at a very high pressure of 140 bar (1 400 m water) and a flow rate of 2.4 l/s. The central jet type pump (Figure 3.3) used in this investigation is applied extensively in marine dredging operations. The central jet pump can operate at a much lower head and is more effective for pumping larger sediment/gravel sizes.

The sediment in the river is coarse (median grain size of approximately 800 micron - refer Figure A1 in Appendix A).

vi) Thulamahashe (Mutlumuvi) Intake (near Bushbuckridge).

Figure 5.5 below shows the Thulamahashe intake. The intake comprises a vertical shaft sump in which two multi-stage vertical spindle pumps are mounted. The pump sump is connected to the river by means of a 1.5 m x 1.5 m culvert with a coarse screen at the end.

Figure 5.5 : Thulamahashe Intake on a tributary of the Sabie River

The intake is located about 50 m upstream of a weir. The weir causes significant settlement of sand on the riverbed to such an extent that the intake end of the culvert is partially blocked. The sediment is transported via the culvert and via the pumps to the purification works where it has to be removed from time to time. After minor and major floods the intake end of the culvert is completely blocked. Pumps operated by divers then have to be used to remove the sand at the intake end, from inside the intake culvert as well as in the pump sump.

The capital cost of each of the pumps is approximately R200 000 and the repair costs (due to damage from sediment entrainment) are approximately R70 000 every 2 months.

vii) Sand River Intake (Bushbuckridge)

Figure 5.6 below presents the Sand River intake. Sand at the intake has to be removed frequently to prevent sand being fed into the pumps or complete blockage of the system.

Figure 5.6 : Sand River Intake (the Sand River is a tributary of the Sabie River). Extensive sand banks in the river course are visible.

The pump station comprises two conventional multi-stage KSB pumps (costing approximately R35 000 each) with suction pipes initially accommodated in a circular concrete sump but due to frequent siltation of the sump the suction pipes had to be extended beyond the sump (refer to Figure 5.6).

The pumps operate at a head of about 60 m with a flow rate of about 70 litres per second. The sediment grain size in the river is coarse (grain size of approximately 1000 micron).

viii) Dwarsloop Intake (near Bushbuckridge)

The location of the intake pipe suction end is shown in Figure 5.7 below. The suction end of the pipe of the pumping station is located upstream of a dam/weir wall. Due to the high sediment load of the river in which the dam is located, sedimentation in the reservoir has occurred at a rapid rate. Due to the low location of the intake pipe through the wall (as is evident in Figure 5.7) and the rapid sedimentation rate the intake pipe soon became buried in the sediment which accumulated upstream of the wall.

Figure 5.7 : Dwarsloop intake (intake pipe is visible on left side where it passes through the weir at a relatively low elevation)

This situation necessitates frequent removal of sediment from the intake end of the intake pipe (a crater is dredged in the sediment at the intake pipe end to allow clear water to enter the system).

The median sediment grain size is approximately 200 micron with approximately 15% silt content.

5.2.2 Water Boards

Information was obtained by means of telephone interviews with staff members of the Water Boards. This information is treated separately below under the respective Water Boards :

i) Bloem Water (Bloemfontein)

(a) Tienfontein Intake on the Caledon River

Tienfontein Intake on the Caledon River is located upstream of Welbedacht Barrage and experiences serious sedimentation problems. Four vertical spindle pumps operate at a time, each delivering approximately 1 m^3 /s. The abrasion on the impellors due to the sedimentation problem is severe with consequent high maintenance costs. At the time of this investigation the impellors of four pumps were being replaced at a total cost of approximately R2.5 million. The pumping station is part of a water transfer scheme and does not operate continuously but only when required during droughts.

(b) Welbedacht Barrage on the Caledon River

The Welbedacht intake at the barrage is now beginning to experience sedimentation problems due to extensive extent of sedimentation within the Welbedacht storage basin.

(c) Bethulie Intake

This intake is situated at a bridge prier and comprises a vertical shaft of about 2.5 m by 3 m in which three pumps are accommodated. The pumping rate is 18 l/s at 80 m head on a continuous basis. The pump sump has a conical floor and a jet pump is permanently installed at the deepest location of the conical floor. The sediment consists mainly of silt. The silt (when settled and left in a settled state for a period of time) becomes cohesive which makes it difficult to remove, by pumping. Arching of the sediment at the jet pump suction end occurs. Arching occurs because the silt is not disintegrated sufficiently for it to flow towards the jet pump suction end.

ii) Overberg Water Board (Heidelberg, Western Cape)

The Overberg Water Board experiences sediment problems at the Duiwenhoks River intake near Heidelberg. The system comprises of two Flygt pumps with a combined pumping rate of approximately 70 l/s.

The intake is located upstream of a small weir on a river bend. The river is sediment laden and shifting sand banks is part of the cause of the problem.

iii) Rand Water Board (Johannesburg)

The Rand Water Board experiences sedimentation problems at their intakes which are not frequently used (i.e. the 2 intakes at the Vaal Barrage and the Suikerbosch intake). These intakes have to be backwashed to remove the sediment from the intakes before they are used.

iv) Umgeni Water Board (Pietermaritzburg)

Umgeni Water Board's main intakes are situated within large dams where they do not experience sedimentation problems. However, at three of their smaller rural intakes (i.e. at Umkomaas, Mtwalume and Mzimaya), where water is abstracted from low flowing rivers (flow depth of in the order of 0.5 m) they do experience sediment problems at the water intakes.

Flow rates are in the order of 40 l/s. They use conventional borehole screens (stainless steel, wedge wire type screens) at the intake suction end of the intake pumps. The size of the screens used are 100 mm diameter by 4 m long. The screens are placed on the river bed and the suction pipes connected to them are of a flexible type. Sediment entrainment is limited by limiting the flow velocity through the screen openings.

v) Lepelle Northern Water (Phalaborwa)

The Olifantspoort intake is located just upstream of a weir in the Olifants River. Water is abstracted near the surface of the overflow across the weir. The water flows through a settling basin with a V-shaped floor where settlement of sediment takes place after which the water flows into a pumping sump where vertical spindle pumps are located.

The settling basin with the V-shaped floor is equipped with a permanently installed jet pump (Crown Plate type) with a sensor that switches the jet pump on when the settled sediment surface in the settling basin reaches a specified level. The jet pump discharges the sediment on the downstream side of the weir into the river.

It has been reported that problems are still being experienced due to excessive sediment accretion on the river bed upstream (outside) of the intake to the settling basin.

5.2.3 Municipalities

The only municipality which has been approached was Upington Municipality.

Their main sedimentation problem is experienced in the settling basins of the raw water intake system. Water is pumped from the river to a canal where a high flow velocity is maintained to prevent settlement. Water then flows into a large settling basin comprising of 36 settling cones (3 cones in the cross direction and 12 cones in the long direction). The overall dimension of the settling basin is 8 m wide by 30 m long. Coarse sand settles out within the first 6 cones while finer sand and silt settle out in the last 30 cones. The sediment is drained from the cones by means of rubber pipes, connected to the lower ends of the cones, on a frequent basis. Problems are experienced with draining of the cones containing the coarser sand (probably due to bridging over the outlet). Different methods such as injection of air is used to assist emptying of these cones, but with difficulty.

5.3 DISCUSSION AND CONCLUSIONS REGARDING THE INVESTIGATION OF PROBLEM CASES

5.3.1 Discussion of problem cases

The information obtained revealed the following important issues with respect to intakes located on sediment laden rivers :

i) There is a need for systems to overcome sedimentation problems at pumping intakes on rivers.

ii) Many of the smaller intakes (specifically the intakes in rural areas) are remotely located with minimum local infrastructure and poor roads.

iii) Operation and maintenance of most rural intake pumping stations are performed by semi-skilled staff.

iv) Sediment passing through pump intakes often causes abrasion damage to pumps with consequent high operating costs.

v) Both major and minor floods can cause blockage or disruption of water abstraction intakes particularly on smaller rivers.

vi) Sediment problems in some cases could be limited by structurally modifying the existing intake works towards more effective designs with due regard to local hydraulic and sediment dynamics/morphology. However, it is considered that even in cases of hydraulically well-designed intakes, some degree of localised sedimentation is bound to occur. In such a case a jet-type pump would assist in the removal of localised sedimentation.

vii) In the case of small rural intakes remotely located with minimum infrastructure and poor access roads, it is considered that permanently installed sediment removal systems will be appropriate.

viii) In cases with better local infrastructure (including good road access) a transportable sediment removal system which could serve more than one intake in an area, could be more appropriate.

5.3.2 Conclusions on problem cases

The following problem cases were identified as good examples for the implementation of the alternative applications of jet type dredge pumps. :

i) The Sand River Intake is a typical case for the application of a permanently installed (fixed) sediment removal system.

ii) The Sabie River (Nsikazi North) Intake is a typical case for the application of a mobile sediment removal system where sediment could be removed after each flood to prevent sediment from entering the intake pipe and pump sump.

6. DESIGN DETAILS AND COMPOSITION OF TEST SYSTEMS

6.1 INTRODUCTION

Based on the conclusions reached in Section 5 it was decided to design, procure the necessary components and assemble a fixed test system for the Sand River Intake as well as a mobile trailer-mounted test system for cases such as the Sabie River (Nsikazi North) Intake for evaluation at the selected sites.

The units were designed as experimental units to be utilised in this investigation, the purpose of which was to establish if the jet type dredge pump is an appropriate tool to remove sediment from intakes on rivers. The details of the units presented below must therefore be viewed as the details of experimental units.

The jet type dredge pump of GENFLO (Pty) Ltd was selected based on successful experience with it in the marine environment. [The CH WARMAN PUMP GROUP is an alternative supplier of jet type dredge pumps. The WARMAN Model 100 JPJ ® is of similar capacity as the GENFLO jet pump referred to above. The MONO positive displacement pump was selected as the motive pump to drive the jet pump because of its good suction characteristics, reliability and ease of maintenance. To enable thorough supervision a pump supplier/contractor in Cape Town (Wm Spilhaus & Co (WP) Ltd) was selected to perform the assembly of systems as specified by the project team.

6.2 SPECIFIC DESIGN DETAIL OF JET PUMPS FOR BOTH FIXED AND MOBILE TEST SYSTEMS

Both the fixed and mobile (trailer mounted) jet pump systems were designed for the design conditions presented in Table 6.1 below (refer Figure 3.3 for the basic components of a jet-type dredge pump) :

Table 6.1 : Design technical detail of fixed and mobile jet pump systems

COMPONENT PARAMETER	TECHNICAL DETAIL
Production Rate	30 t/h (approx 18 m^3 bulk volume sand per hour
Supply head of motive pump	700 kPa
Supply flow rate to main jet	10 litres/second
Supply flow rate to fluidizer nozzle	2.5 litres/second
Induced suction flow rate	9 litres/second
Head at diffuser outlet	11.7 m
Mixing Chamber diameter	44 mm
Jet pump grid size at suction end	30 mm x 30 mm
Main jet diameter	19 mm
Motive pipe length	50 m
Motive pipe diameter	100 mm
Motive pipe velocity	1.5 m/s
Motive pipe friction head loss	2.5 m per 100 m pipe length
Jet pump depth below water surface	3 m
Discharge pipe length	50 m
Discharge line diameter	100 mm
Discharge pipe flow velocity	2.5 m/s
Discharge pipe end elevation above water level	5 m
Friction loss in discharge pipe	8.8 m / 100 m
Discharge sediment concentration by mass	31 %
Energy rate consumption per ton removed	3.2 kW/t.h
Design grain size distribution	D15 = 0.155 mm
	D50 = 0.212 mm
	D75 = 0.242 mm
	Maximum size = 30 mm
Sand specific gravity	2.65

The jet type dredge permit SANDBUG® (obtained from GENFLO (Pty) Ltd) operating under the above design conditions was selected for both the fixed and mobile trailer mounted test plants. The SANDBUG® can operate between 500 kPa and 800 kPa motive pressure with corresponding variation in production rates. The overall dimensions of the SANDBUG® are 1100 mm long by 400 mm wide by 250 mm thick, with a mass of 45 kg. Figure 6.1 below shows the SANDBUG® jet pump.

Figure 6.1 : GENFLO (Pty) Ltd's Sandbug® Jet Type Dredge Pump. (The jet pump is the dark blue component with upper half of its cowl removed).

The alternative jet type dredge pump of similar capacity and size of CH WARMAN PUMP GROUP is shown in Figure 6.2 below. This model (100 JPJ ®) is manufactured in a special plastic material with a total mass of 15 kg.

Figure 6.2 : CH WARMAN PUMP GROUP's Jet Type Pump (Model 100 JPJ®).

The intake end of the jet pump is provided with a screen/grid that prevents particles larger than the maximum sediment/gravel size of 30 mm diameter to enter the suction end of the jet pump. Due to this limitation there is a tendency for so-called "nesting" of particle gravel sizes larger than 30 mm around the intake end of the jet pump. For the purpose of breaking up the "nesting" of larger gravel sizes an isolating valve is normally fitted at any location on the discharge pipe of the jet pump. Closing of this valve causes a backwash action through the jet pump intake screen which breaks up the "nesting" of larger gravel sizes around the intake and of the jet pump.

6.3 MOBILE TRAILER MOUNTED PILOT PLANT

6.3.1 Technical design detail of mobile plant

The trailer mounted jet pump system for the test pilot unit is presented schematically in Figure 6.3 below.

The trailer accommodates the motive pump, with a diesel engine that drives the jet pump, compressor and vacuum pump used for priming of the motive pump and for changing the buoyancy of the jet pump's variable tank. Provision was also made on the trailer to accommodate all pipes, buoys, tools and specials, as well as the jet pump as a self-contained unit.

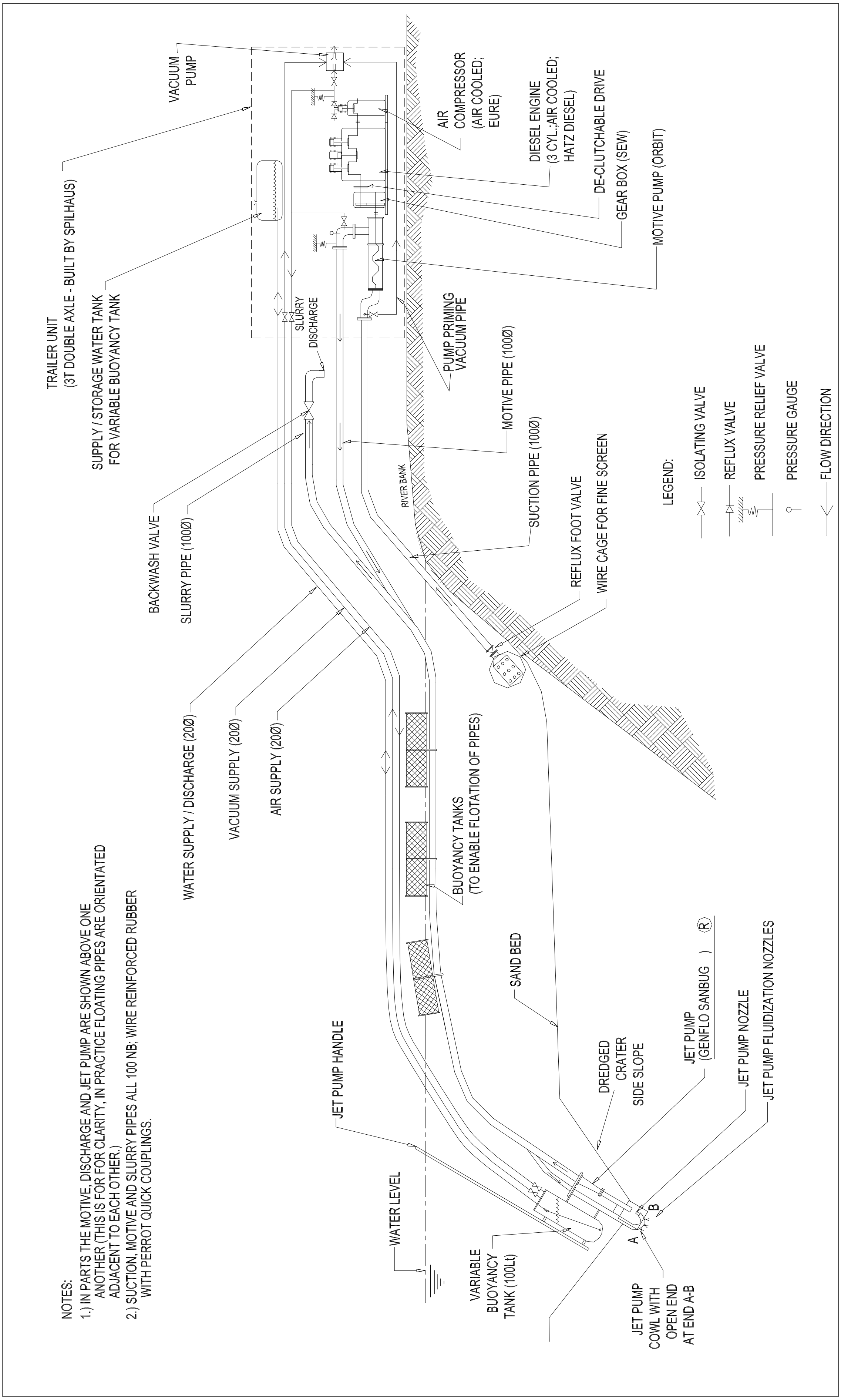

Figure 6.3 : Schematic diagram of mobile (trailer mounted) test plant

The trailer unit in operation at the Sand River intake (pipes unloaded and motive pump running) is shown in Figure 6.4 below.

Figure 6.4 : Mobile trailer mounted test unit in operation (pipes unloaded and motive pump running)

The technical details of the mobile trailer mounted test unit are presented below in Table 6.2

Table 6.2 : Technical detail of mobile trailer mounted test unit

COMPONENT PARAMETER	**TECHNICAL DETAIL**
Motive pump type	Orbit positive displacement pump
Motive pump duty point	Discharge rate = 12.5 litres/second Head = 700 kPa
Motive pump solids handling capacity	soft and compressible = 40 mm diameter angular = 10 mm diameter
Rated power	11 kW
NPSH required	3.3 m
Diesel engine : Make Model	Hatz diesel, 3 cylinder, air cooled 3 M40
Power Mass Overall dimensions	22 kW at 1500 rpm 291 kg 753 mm x 550 mm x 733 mm high
Gear box ratio to drive pump via de-clutchable coupling on diesel engine	 1:1.93
Gearbox make and model	SEW, Eurodrive model RX 87ADS
Compressor make (driven by diesel engine) Power requirement Operating pressure Safety valve setting Compressor air displacement rate Compressor speed	CE, Eure s.r.l. model B2600 B 2.2 kW 110 kPa 90 kPa 321 litres/minute 1500 rpm
Vacuum pump make and model Required compressed air feed pressure Suction rate at – 6.0 m head	PIAB, Classic model M50 350 kPa 0.6 N litres/second
Operating principle	Venturi suction
Pipe length, type and diameters : All pipes nominal diameter All pipes working pressure Wire reinforced pipe total length Layflat pipe length	 100 mm 100 kPa 8 x 6 m lengths with PERROT quick couplings 2 x 12 m lengths with PERROT quick couplings
Buoys for making pipes float Pressure relief valve on motive supply line make and rating	25 litres plastic drums BIRKETT spring set at 800 kPa

The suction end of the motive supply pump was provided with a foot valve and a fine screen (3 mm square openings) to prevent blockage of the jet pump's fluidizer nozzles (fluidizer nozzle's diameter = 5 mm).

The jet pump discharge pipe was provided with a butterfly isolating valve for backwash purposes of the jet pump. (Backwashing is necessary when gravel sizes larger than the jet pump screen "nest" around the intake end of the jet pump).

The jet pump of the mobile system was fixed to a 100 litre variable buoyancy tank to enable the jet pump to either float or to descend to the river bed. The buoyancy tank and handle were manufactured of aluminium. The size of the tank was 300 mm diameter and 1.5 long. The handle welded to the tank was 1.0 m longer than the tank and made up of 30 mm diameter aluminium pipe. The buoyancy of the tank is regulated by means of either supplying compressed air to the tank (which displaces the water in the tank via a pipe to a storage tank on the trailer) or by applying vacuum to the tank (which allows water in the storage tank on the trailer to flow back to the tank). The variable buoyancy system is shown schematically in Figure 6.3. The buoyancy and storage tanks were connected through three compressed air type hoses (yellow) of 12 mm diameter. Buoyancy control could be exercised either at the buoyancy tank or at the trailer.

To enable pipes connected to the jet pump and its buoyancy tank to float, 25 litres plastic drums with special clip-on ties were provided to be attached at frequent intervals to the pipes.

The 2001 capital cost of the mobile unit was R155 970.00 (excl. VAT). In addition to the capital cost, the transport costs from Cape Town to Nelspruit amounted to R15 624.00.

The mobile system and all its accessories were mounted on a double axle trailer with a 3-ton carrying capacity. The total mass of the trailer system with all its pipes and accessories was 2.3 ton. It could be transported on a truck. (Transport of the system by truck is advisable when transport is required over long distances such as from Cape Town to Nelspruit). The normal transport mode is by means of towing with a 4 wheel drive LDV enabling it to be transported over rough terrain to be located as close as possible to the river bank near the area in a river to be dredged.

6.3.2 Operation of mobile system

Figure 6.3 depicts the operation of the system.

After the trailer has been appropriately positioned at the river bank the jet pump and pipes are off-loaded and connected on the river bank. The suction pipe end of the motive pipe is placed in a convenient place in the river water. The diesel engine is then started (with the drive to the pump unclutched) and with the compressor and vacuum pump operational, the suction pipe of the motive pump is primed by extracting the air from the pipe of the suction pump by means of the vacuum pump on the trailer. The jet pump is then placed in the river in the buoyant mode (floating mode). Engaging the clutch between the engine and the gearbox activates the motive pump which drives the jet pump. The jet pump can be made to descend to the river bed by decreasing the buoyancy of the buoyancy tank. This is done by extracting air from the buoyancy tank with the vacuum pump and allowing water from the water tank on the trailer to enter the buoyancy tank.

The mobile trailer system can be operated by two divers and two semi-skilled labourers. When the jet pump is in operation mode (as shown in Figure 6.3) it can be left unattended for a considerable period before it is necessary to move it to the next position. Movement of the jet pump is made easier by letting it float (increasing the buoyancy of the variable buoyancy tanks) by injecting compressed air into the buoyancy tank (by means of the compressor on the trailer) which displaces water from the tank. The jet pump is then moved to a new position where its buoyancy is again decreased to enable it to descend to the river bed.

It is possible to relocate the jet pump without divers in cases where there is sufficient depth. When the jet pump is in floating mode it can be moved to a new position by means of a light boat (e.g. "rubber duck" type boat) where the variable buoyancy tank's buoyancy can be decreased to enable the jet pump to dive into the sand bed to enable dredging at the location. [This is the operational method for maintenance dredging at the Club Mykonos Langebaan Small Craft Harbour – Prestedge and Bosman, (1994)].

The jet pump operates most effectively when its suction end is buried in the sand bed. If the dredged sand is free flowing, the jet pump creates a conical crater with the jet pump operating at the bottom of the crater. Free flowing sand has an approximate repose slope below water of approximately 1.5 horizontal to 1.0 vertical. To remove sand from an area it is dredged by means of a series of overlapping craters (crater-mode-dredging).

In the case of dredging of silt/clay material the angle of repose of crater side slopes tends to be steep. To cause the slumping of steep side slopes the disintegration nozzles of the jet pump (normally jetting downwards) can be arranged so that a number of nozzles jet downwards and some nozzles sidewards. The sideward jetting of disintegration nozzles will undermine the side slopes causing them to collapse which will increase the jet pump's influence zone in a crater.

The dredged sand can be either discharged downstream of the dredged area in the river or it could be discharged onto the river bank in a containment dam. The containment dam could be formed by earth walls from local soil or the dredged sand which is also suitable for this purpose. The water effluent from the containment dam can be decanted via an appropriately designed overflow weir to ensure that the solids concentration in the overflow which enters the river satisfies the water quality criteria standards. The environmental impact issues of dredging effluent are discussed in detail in Chapter 8.

6.4 TRANSPORTABLE FIXED TEST PLANT

6.4.1 Technical detail of fixed plant

The transportable fixed test plant (same jet pump size as for the mobile unit described in paragraph 6.2) is presented schematically in Figure 6.5 below as it has been installed at the Sand River intake. Since the pumping head of the raw water pumps at the Sand River intake is approximately 600 kPa (which is close to the design head of the jet pump) it was considered suitable to drive the fixed pilot plant in this study. The delivery rate of the raw water pump station is estimated at approximately 70 litres/second. Since the jet pump only requires 12 litres/second on an intermittent basis it only uses a relatively small percentage of the raw water supply. The connection of the discharge pipe of the raw water pumps at the Sand River intake to the fixed jet pump system at the suction pipe ends of the raw water pumps is shown in Figure 6.6 below.

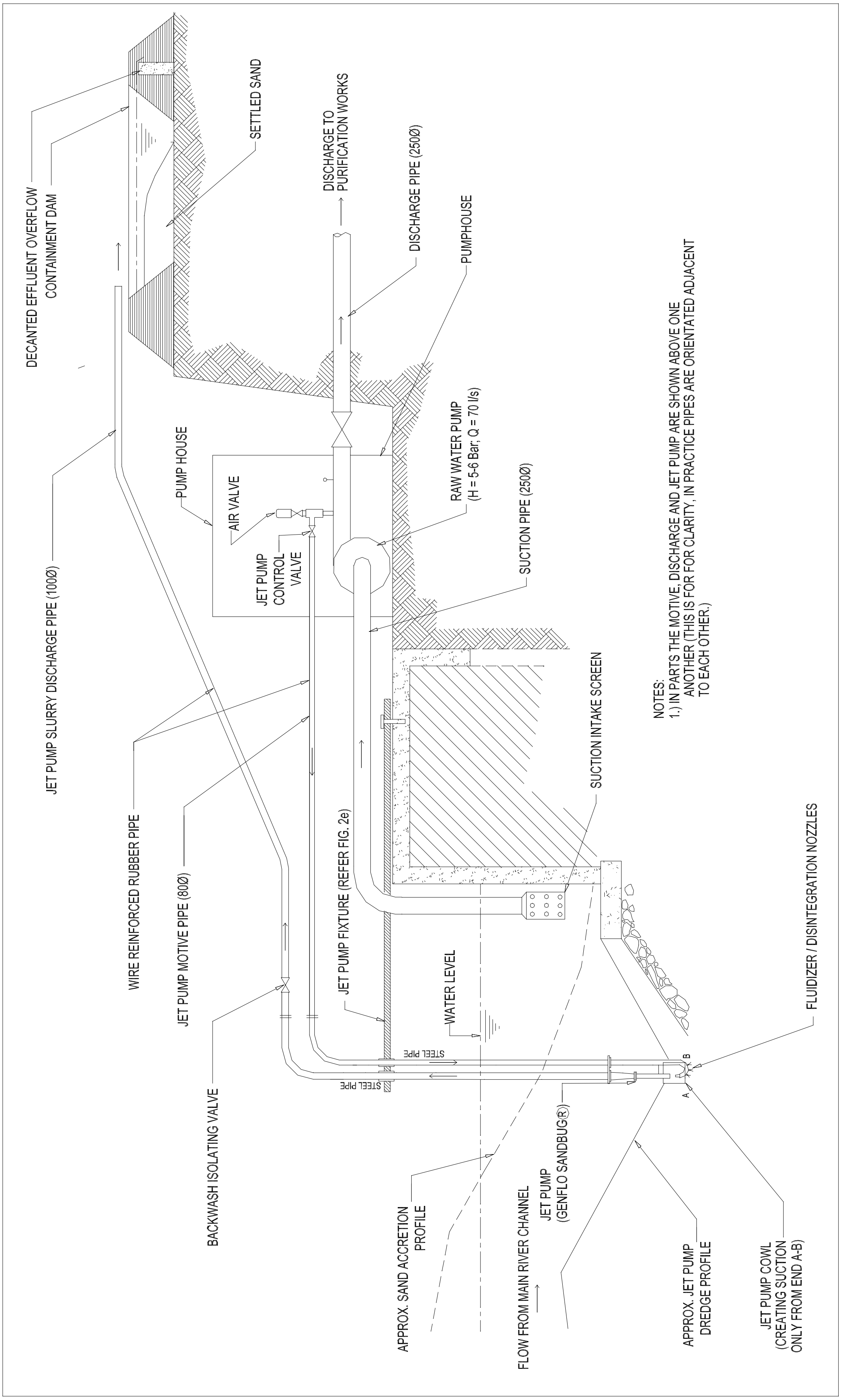

Figure 6.5 : Schematic diagram of transportable fixed plant at Sand River Intake

Figure 6.6 : The tap-off of the fixed pump's motive pipe from the raw water discharge pipe at the Sand River intake pumphouse. (Sandbank in river visible in background).

The fixed test pilot plant's technical details are presented in Table 6.3 below (system as installed at the Sand River Intake) :

Table 6.3 : Technical detail of fixed test pilot jet pump

COMPONENT / PARAMETER	TECHNICAL DETAIL
Motive supply head (take off from existing air valve socket on main discharge pipe – see Figure 6.6	600 kPa
Motive pipe (horizontal) Type Length Diameter	 wire reinforced rubble 12 m 80 mm
Motive pipe vertical Type Length Diameter	 galv. steel 2.5 m 80 mm
Depth of Jet Pump Intake End	1.5 m below raw water pump intake
Jet Pump Discharge Pipe (Vertical) Type Length Diameter	 galv. steel 2.5 m 100 mm
Jet Pump Discharge Pipe (between jet pump and backwash isolating valve) Type Length Diameter	 wire reinforced rubble 3 m 100 mm
Jet Pump Discharge Pipe (horizontal between backwash valve and discharge end Type Length Diameter	 layflat (fire hose type) 12 m 100 mm

The 2001 capital cost of the fixed system including pipe work and jet pump was R29 086.00 (excl VAT).

6.4.2 Operation of Fixed System

The jet pump is fixed in a permanent position but can swivel horizontally to cover the zone between the two raw water intake pipes. The fixed pump system can be activated by opening the jet pump control valve (Figure 6.5) when the raw water pumps are operating.

The discharge pipeline is provided with an isolating valve (Figure 6.5) to enable backwashing of the jet pump (to clear the jet pump intake from obstructions when required). The discharge pipeline discharges approximately 12 m downstream of the intake onto the river bank with the sand settling on the landward side of a reed zone on the river bank. The effluent water flows back into the river via the reed zone which acts as a natural filter limiting turbid water entering the river.

For illustrative purposes Figure 6.5 shows the jet pump discharging into a containment dam with a decanting effluent overflow to control turbid effluent from entering the river. In this case the opportunity of selling the clean settled sand as building sand exists, the income from which could be used to offset operational costs.

The environmental issues related to sediment removal and discharge are treated in detail in Paragraph 8.

7. DESCRIPTION AND EVALUATION OF FIELD TEST RESULTS

7.1 MOBILE TRAILER MOUNTED SYSTEM

7.1.1 Initial evaluation tests of mobile unit during commissioning week (12 to 16 March 2001)

i) Commissioning of Sabie River Intake

The pilot plant was successfully commissioned at the Sabie River Intake (Figure 7.1 below) on 12 March 2001. A 2 m thick sand layer at the intake was dredged and a crater was dredged on the river side of the intake to create a sand trapping volume enabling the intake to remain sediment free for a period.

Figure 7.1 : Test pilot plant in operation at the Sabie River Intake (Refer also to Figure 5.4 which shows the intake viewed from the river side).

The pumping operation commenced at 13:00 and was terminated at 16:30. An estimated volume of approximately 40 m^3 of sand was dredged with a resulting pumping rate of approximately 11 cubic metres per hour. Sand was discharged on to the river bank in a shrub area where the sand settled and the water effluent from the dredged sand filtered through the shrubs before entering the river. The shrubs acted as a filter, filtering the effluent from the settled sand to such an extent that the concentration of solids in the effluent which entered the river was acceptably low.

ii) Dredging at the Sand River Intake

To enable installation of the fixed pilot plant at the Sand River intake, the accreted sand, at the intake had to be dredged by means of the mobile unit in order to create a crater as is shown schematically in Figure 6.5. Figure 7.2 shows dredging of the crater in progress at the Sand River intake on 13 March 2001. Dredging commenced at approximately 13:30 and was completed at 16:30. An estimated volume of 35 m^3 of sand was dredged which implied a pumping rate of approximately 12 m^3/h.

Figure 7.2 : Dredging of a crater by means of the mobile trailer unit in progress at the Sand River Intake

Since the sand was relatively free of silt the dredged sand was discharged to the downstream side of an existing sandbank as shown in Figure 7.2. Since the sediment being dredged was relatively coarse, the amount of turbidity caused by the effluent from the dredged sand was low.

iii) Dredging at Hoxani Intake

The Hoxani raw water intake in the Sabie River comprises of four submersible pumps, accommodated in a concrete structure (Figure 5.3). Sand tends to accrete both on the outside and inside of the concrete intake structure. This accretion of sand in the intake frequently causes the raw water pumps to pump significant quantities of sand to the purification works. The consequence is abrasion of the submersible pumps and clogging of the purification works with sand.

On 15 March 2001 the mobile unit was employed to remove an accreted sand layer, approximately 1.5 m thick inside the intake structure, upstream of the pumps. The estimated volume removed was approximately 20 m^3. Since the floor of the existing concrete intake structure is flat, the fluidisation nozzles of the jet pump tended to jet the sand away from the jet pump suction end when the sand depth on the floor was reduced to approximately 200 mm. Since the jet pump can operate without fluidisation jets in loose sand, three of the five nozzles were closed to enable the removal of the thin remaining layer of sand on the flat floor of the intake structure.

To confirm that the mobile unit can function with the trailer, remotely located from the jet pump, additional pipe was used to extend the motive pipeline to a length of approximately 70 m. The jet pump still operated satisfactory but due to the longer motive pipeline (causing a larger friction head) the motive pump's discharge pressure increased from the normal 800 kPa to approximately 100 kPa.

iv) Dredging at Dwarsloop Intake

On 16 March the mobile unit was used to dredge a crater at the intake pipe end on the upstream side of Dwarsloop weir (Figure 5.3). A volume of approximately 25 m^3 was dredged between 8:00 and 13:00. Since the sediment mainly comprised silt, the side slopes of the dredged crater tended to be steep and therefore divers had to assist the flowing of the silt towards the jet pump intake end. To assist the collapsing/ disintegration of the silt side slopes of the dredge crater, it is considered that the orientation of the jet pumps disintegration nozzles will be more effective if some of the nozzles were to jet sideways in order to undermine the crater slopes at their toe level and thus causing the side slopes to collapse.

7.1.2 Summary of mobile unit's evaluation dredging tests, during the commissioning week and subsequent dredging operations

The mobile sediment removal unit was used successfully by the contractor Trans Oos Motor & Engineering at a number of problem sites during the period March 2001 to March 2002. The contractor was commissioned for a total about 17 work packages during this period by DWAF who kept the project leader informed regarding progress during this period. The contractor's operating team comprised of a diving supervisor, two divers and two semi-skilled labourers. When clearing operations on more than one intake in an area required an operating period of longer than one day, the contractor set up camp to reduce the transport costs.

An operation from one camp on a number of installations was defined as a "work package". The operating team normally made use of two LDV's to transport the mobile unit, operating staff and equipment. The nett daily rate to operate the mobile plant was R1 500 (incl. VAT) with one skilled supervisor and two semi-skilled labourers. In cases where divers were required (two divers with one supervisor) the cost per day amounted to R3 600 (incl. VAT). Depending on the location of the sites the additional cost for transport and camping allowances amounted to approximately R1 500 per day (incl. VAT).

A summary of work packages carried out by the contractor during a period of approximately 12 months at 8 sites is presented as an example in Table 7.1 below to illustrate the order of magnitude of operating costs.

Table 7.1 : Summary of work packages carried out by the mobile jet pump system

Work Package	Period	Installations Cleared (work package)	Amount (incl VAT)
1	12 - 17 March 01 (5 days)	Nsikazi North (Sabie River) Sand River Hoxani Intake Dwarsloop	R25 493.80
2	19 March - 04 April 01 (13 days)	Sand River Mutlumuvi (Thulamahase) Nsikazi North Hoxani Purification Works *	R88 000.00
3	21 - 25 May 01 (5 days)	Mutali Weir Intake (Thoyandou - near Tzaneen)	R29 969.46
4	30 May - 01 June 01 (3 days)	Nsikazi North (Sabie River)	R11 382.90
5	5 - 11 June 01 (5 days)	Hoxani Intake Hoxani Purification Works * Dwarsloop Intake Sand River Intake Mutlumuvi (Thulamahase)	R27 336.74
6	July 01 (5 days)	Weltevreden Dam Intake	R27 779.52
7	16-19 July 01 (4 days)	Hoxani Intake Hoxani Purification Works *	R17 068.76

Work Package	Period	Installations Cleared (work package)	Amount (incl VAT)
8	23-27 July 01 5 days)	Mutlumuvi (Thulamahase)	R23 487.65
9	2 - 3 August 01 (2 days)	Sand River Intake	R7 710.96
10	21 - 23 August 01 (2 days)	Nsikazi North (Sabie River) Intake and Sump Clearance	R12 659.70
11	3 - 7 Sept 01 (4 days)	Hoxani Intake Hoxani Purification Works *	R17 088.60
12	Oct 01	Sand River Intake (2 days) Mutlumuvi Intake (2 days) Nsitazi North (Sabie River) (2 days) Hoxani Intake (3 days) Hoxani Purification Works (1 day) * Thulamashe Purification Works (2 days) *	R73 427.62
13	Nov 01	Hoxani Intake (5 days)	R21 517.50
14	Dec 01	Hoxani Intake (10 days)	R42 385.20
15	Jan 02	Nsitazi North Intake (2 days) 100 hour servicing of mobile jet pump system including replacement of backwash valve (R1610). Hoxani Intake (6 days) Hoxani Purification works (2 days) *	R41 115.87
16	Feb 02	Sand River Intake (4 days) Hoxani Intake (1 day)	R23 430.65
17	Mar 02	Hoxani Intake (2 days)	R16 763.70
TOTALS	97 working days	38 clearings	R506 618.63

Notes: 1. Sites indicated by * did not require divers

2. All costs relate to the years 2001 and 2002 as indicated

The work packages included a number of sites. In most cases a number of sites were included in one work package since the stations were in close proximity and the working team could operate from a central camping site.

The average daily operating cost including labour, fuel and maintenance of the equipment are estimated as follows :

- where divers are required : R6000 / day (incl VAT)
- where divers are not required : R3000 / day (incl VAT)

The rate of R6000/day where divers are required includes standby and working rates for divers during the cleaning operation periods.

The frequency of cleaning required by the 8 pumping sites served by the mobile unit in the Mpumalanga and Northern Province area during the operating period of approximately one year was observed to be about 3 times greater during the rainy season than during the period outside the normal rainy season.

It was not possible in this study to do a direct cost comparison between maintenance costs of the pumps at sediment prone intakes **without** sand removal versus the pump maintenance cost **with** sand removal by means of the mobile test unit.

Although the above sediment removal costs by means of the mobile unit appear to be relatively high they must be considered against the costs of sediment induced repair work. A main benefit and function of the mobile unit is sand removal from sediment prone intakes to enable continuous water supply to consumers without long water supply interruptions. The mobile unit is also considered to be an appropriate tool to use in emergency cases. For the purpose of long term sedimentation removal from sediment prone intakes, a fixed (or dedicated) type installation is considered to be the more appropriate application of the jet pump.

From the information on cost as obtained from this study, an indication of the relationship between the dredging costs to clear intakes from sand, and the capital costs of the raw water pump as well as the pump repair costs and pump repair time could be established. The approximate costs (2002 costs) for the Hoxani raw water pump intake is used to illustrate this relationship :

- Capital cost of 4 new raw water pumps : R200 000 each
- Cost to repair one pump : R100 000
- Time involved in repair : approximately 2 months
- In the case of the Hoxani intake one day (at a cost of R6000) is required to clean the intake.

7.2 TRANSPORTABLE FIXED SYSTEM

7.2.1 Initial evaluation tests of fixed unit during commissioning week (12 to 16 March 2001)

As indicated in paragraph 7.1.1. (ii) the mobile plant was used during the commissioning week to dredge a crater enabling the installation of the fixed plant at the Sand River Intake as shown in Figure 6.5.

The fixed plant was successfully commissioned after which it was operated intermittently as required to evaluate the reliability of its operation. However, relatively clear water was pumped by the fixed plant during most of this period since the crater (dredged by the mobile plant for its installation) was deeper than the installed depth of the fixed plant.

7.2.2 Evaluation of the fixed plant after the commissioning week

The fixed plant was operated more frequently during the rainy season than outside the rainy season. The fixed pump removed the sand successfully in a crater configuration around the intake pumps as shown in Figure 6.5. However, mainly because of a receding river water level during the period outside the rainy season and filling of the crater during flash floods within the rainy season, the mobile unit was also required to dredge a channel between the crater (created by the fixed plant) and the main flow channel to enable water to reach the intake.

Although not attempted in this study, it is considered that two or three additional permanently installed jet pumps between the crater at the intake pipes and the main river channel could maintain a connecting channel to ensure continuous water supply to the intake. In the long term such an arrangement would be significantly cheaper than maintaining a connection channel with a mobile unit.

The operating cost of the fixed plant was minimal because of its infrequent use and the short periods required to create a crater. Only about 15% of the raw water pump's discharge was used intermittently to drive the fixed jet pump at the time when removal of sand was required.

As indicated under Section 7.1.2, for the purpose of long term sedimentation removal from sediment prone intakes, a fixed (or dedicated) type installation is considered to be the more appropriate application of the jet pump.

8 ENVIRONMENTAL ISSUES REGARDING THE DISPOSAL OF SEDIMENT BEING DREDGED AT RIVER INTAKES

There are specific legal requirements to be met when effluent is discharged into South African rivers. The activity of sediment removal from intakes on rivers and either discharging the sediment back into the river or accumulating it on the river bank with effluent water discharging from the accumulated sediment into the river, is subject to legal requirements. Clay/silt type sediments usually contain organic material which could turn anaerobic with constituents that could negatively impact on the river ecology.

For the purpose of describing the legal background to the above environmental issue (Scarr et al, 2002) is quoted (italic portion) as follows:

"The Bill of Rights in the Constitution of the Republic of South Africa declares that everyone has the right to have the environment protected for the benefit of present and future generations. This is done through reasonable legislative measures that promote conservation and secure ecologically sustainable development and use of natural resources, while promoting justifiable economic and social development (Section 24 of Act 108 of 1996).

Statutes which may be applicable to sediment removal from river intakes on South African rivers include:

- *The National Environment Management Act (Act 108 of 1998), or NEMA*
- *The Environment Conservation Act (Act 73 of 1989), or ECA*
- *The National Water Act (Act 36 of 1998), or NWA*

It must also be recognised that, depending on the exact nature of any particular sediment management initiative, provisions of other legislation such as the Minerals Act (Act 50 of 1991) and the various provincial planning ordinances may also be applicable.

In terms of the Act the Minister of Environmental Affairs and Tourism "may by notice in the Gazette identify those activities which in his opinion may have a substantial detrimental effect on the environment, whether in general or in respect of certain areas". Accordingly, Schedule 1 to Government Notice No. R. 1182 of 5 September 1997 (Government Gazette No. 18261) lists activities which the Minister identified in general as activities of this nature.

The following listed activity is relevant in the removal and disposal of sediment from rivers:

The disposal of waste as required in terms of section 20 of the Environmental conservation Act, 1989.

Having made provision for the identification of activities which may have a detrimental effect on the environment, the ECA stipulates that no person shall undertake an identified activity "or cause such an activity to be undertaken except by virtue of a written authorization" issued by the Minister or a competent authority as defined in terms of the Act. A competent authority is effectively the provincial authority to whom administration of the Act has been assigned.

It further stipulates that such authorization "shall only be issued after consideration of reports concerning the impact of the proposed activity and of alternative proposed activities on the environment, which shall be compiled and submitted …… in such manner as prescribed." The Minister or competent authority "may at his or its discretion refuse or grant the authorization …. on such conditions as the Minister or authority may deem necessary." Provision is made for withdrawal of the authorization in the event of specified conditions not being complied with.

Finally, the Act creates the facility for the Minister to make regulations with regard to identified activities, concerning inter alia the scope and content of environmental impact reports, and the evaluation of such reports and of the effect of a proposed activity and alternative activities on the environment.

Arising from this facility, the Schedule of listed activities in Government Notice No. R. 1182 of 1997 is complemented by the environmental impact assessment regulations published as Notice No. R. 1183 of 1997 in the same gazette (with subsequent amendments in October 1997, March 1998 and May 2002). <u>The regulations specify the responsibilities of both applicant and competent authority in relation to the applications for authorization to undertake activities, as well as associated procedures, including the lodging of appeals against the outcome of applications. An applicant must appoint an independent consultant to comply with the regulations on his/her behalf, and emphasis is placed on public participation in the specified process.</u>

The application process involves numerous iterations, and makes provision for ongoing liaison between the applicant's consultant and the authorizing agency. It also grants the latter discretion to determine whether certain of the iterations can be combined or truncated. In general, it could be said that the length and complexity of the impact assessment process is a function of the scale of the envisaged activity, the characteristics and sensitivity of the receiving environment, and the extent to which the project proposal engenders stakeholder reaction.

A fundamental variation in processes conducted in terms of the regulations revolves around whether an authority is able to issue a decision on an application based on the information contained in a scoping report, or whether such information needs to be supplemented by an environmental impact assessment proper. In brief, key components of a scoping report include descriptions of how the environment may be affected by a proposed activity, environmental issues identified, all alternatives identified, and the public participation process followed.

Upon receipt of a scoping report, and after the effecting of any amendments to the report required by the authority, the <u>*authority may issue an authorization with or without conditions*</u>*, or reject the application.*

Alternatively, the authority may require an environmental impact assessment which focuses on the identified alternatives and environmental issues identified in the scoping report. Following the submission of an environmental impact assessment which complies with the requirements specified in the regulations, the authority may, as above, authorize the application with or without conditions, or reject it.

In conclusion, the outcome of an application in terms of the EIA regulations is detailed in a "record of decision" which must be issued on request to any interested party. Provision is made for the lodging of appeals against such decisions."

It is clear from the above legislative background that it is a requirement that the so-called Environmental Impact Assessment (EIA) procedure (refer to the underscored section in the above quote) must be followed in case of sediment removal and discharge back into a river of either the removed sediment or the effluent from accumulated sediment on the river bank.

As a first step towards the EIA procedure, it is advisable to approach the Department of Water Affairs and Forestry (DWAF) for their approval of proposed sediment removal operations which are of direct concern to DWAF. DWAF would then be in a position to either issue a permit or advise if the legally prescribed broader EIA procedure (as administered by the Department of Environment Affairs and Tourism) should be followed.

Environmental issues which need to be addressed in the operation of removal of sediments from water intakes on rivers include :

- Degree of increase in turbidity of river water during sediment removal from the river.

- Degree of increase in turbidity and possible pollution (if removed sediment is toxic) of the river water if effluent from the sediment removal operation is discharged into the river.

- If removed sediment is stock-piled on the river bank, the danger of floods washing the stockpiled sediment back into the river.

9. CONCLUDING REMARKS AND GENERAL GUIDELINES FOR APPLICATION OF JET PUMP TYPE SEDIMENT REMOVAL SYSTEMS

9.1 CONCLUDING REMARKS

The following are the main conclusions of this investigation:

i) There are a significant number of existing river intakes (specifically in the Northern Province and Mpumalanga areas) which are experiencing sediment problems. The smaller intakes located on smaller sediment laden rivers with highly variable flow regimes are most prone to sedimentation problems. Both major and minor floods cause blockage or disruption at many intakes on rivers.

ii) Sediment accumulation at river intakes can cause long interruptions in water supply to consumers and excessive abrasion of pumps with consequent high operating costs.

iii) To protect pumps against excessive wear due to sediments and to ensure continuous water supplies from problem intakes there exists a need for the effective removal of sediment from such river intakes.

iv) The design of both a mobile and a fixed test plant in this investigation was based on the needs and circumstances of existing intakes with sedimentation problems (in the Northern Province and Mpumalanga).

v) The **fixed** test plant installed at the Sand river intake was successful in maintaining a crater around the pump intake pipes to prevent the clogging of the intakes and the entrainment of sand into the raw water pumping system. The **mobile** trailer mounted test plant was used successfully to maintain 8 intake locations on a frequent basis during the evaluation period of approximately 12 months. It can therefore be concluded that the objectives of this research project have been met and that the methodology should find broad application in future.

vi) The capital cost (2001) of the **mobile** test unit amounted to approximately R160 000 (excl. VAT). The average daily operating costs (2001) including labour, fuel and maintenance of the equipment of the mobile unit are approximately as follows:

- where divers are required: R6 000/day (incl. VAT)
- where divers are not required: R3 000/day (incl. VAT)

The average period required to clear an intake is between one and two days.

A direct cost comparison of sediment removal by the mobile unit versus maintenance cost of the pumps during this period was not possible during this study. A main benefit of the mobile unit is the capability to prevent long interruption periods of water supply to consumers. It is considered an appropriate tool for removing sand during emergency situations.

vii) The capital cost (2001) of the **fixed** unit amounted to approximately R30 000 (excl VAT). The operating cost of the fixed unit at the Sand River intake was minimal because of its infrequent use and short periods required intermittently to create a crater. Only about 15% of the discharge of the raw water pumps was required intermittently to drive the fixed jet pump at the time when removal of sand was required. The fact that sand only needed to be pumped for short periods does indicate that a sediment intercepting crater, once created, can prevent serious build-up during low-flow river conditions. The study also indicated that a situation can arise where a series of fixed pumps might be necessary to maintain a connecting channel between the crater at the intake and a new river channel at times when a sand bank forms between the closest river stream and the crater at the intake. The purpose of the creation and maintenance of a connecting channel is to ensure continuous flow to the intake. In the case of large intakes, weirs can be designed to direct low flows towards intakes.

viii) The types of sediment encountered in problem cases varied between silt and coarse sand. In most of the cases coarse sand was encountered which is free flowing underwater with a repose slope of about 1.5 m horizontal to 1 m vertical. In the case of silt which has been settled for a sometime, shear stresses between grain prevent the free flowing of the sediment towards a suction point. Side slopes of dredged craters tend to be steep under such circumstances. This problem could be overcome by dredging silt before shear stresses develop or by means of appropriately adapted disintegration nozzles fitted to the jet pump.

9.2 GENERAL GUIDELINES FOR THE APPLICATION OF JET PUMP TYPE SEDIMENT REMOVAL SYSTEMS

The following general guidelines for sediment removal by jet pump removal systems evolved from this project:

i) Appropriate hydraulic principles as discussed in Chapter 3.1 should be applied in the design of new intakes to prevent or limit sedimentation problems rather than dealing with the problem afterwards.
Sediment problems in some cases could be reduced by modifying civil works towards more effective designs with due regard to local hydraulic and sediment dynamics/morphology. However, it is considered that even in cases of properly designed intakes, some sedimentation is bound to occur. In such cases an effective sediment removal system would serve to deal with localised sedimentation in the intake.

ii) The **mobile** jet pump system is relatively expensive to operate and is considered an appropriate tool for the clearing of existing sediment prone intakes as well as an emergency measure with the main purpose to prevent long interruption periods of water supply to consumers.

iii) For the purpose of long term sediment removal from sediment prone intakes, a **fixed** (or dedicated) type installation is considered the more appropriate application of the jet pump. An example of a water intake system on the Sabie River which was recently designed by DWAF and is being constructed by DWAF during the writing of this report, is presented in Appendix B. The design of the civil works, to minimize sedimentation of the intake pump station, was done according to the principles presented in Chapter 3 of this report. As a 'second line of defence' an appropriately designed fixed jet type sediment removal system was also incorporated in the intake works.

iv) Although jet pump type sediment removal systems can be designed and built in different sizes (dredging capacities from 1.5 t/h to 1 000 t/h) it is considered that the size of the test systems used in this study (dredging capacity of approximately 15 m^3 sediment (bulk) per hour) is an appropriate size for small scale intakes (refer to Chapter 6 for the technical detail of the test systems used in this project).

v) In the case of a fixed jet pump type system, the motive water required to drive the jet pump could be tapped from the raw water discharge pipe if the pressure and discharge of the raw water pump are sufficient to meet the requirements of the jet pump. This was done in the case of the test system at the Sand River Intake (refer to Figure 6.5) as well as the DWAF design of the new intake on the Sabie River (refer Appendix B).

vi) In the design of new intakes consideration should be given in the civil works for the installation of a jet pump or series of jet pumps in locations where sedimentation is expected which cannot be removed by other means. In some cases fixed jet pumps could be installed both **inside** an intake structure and (where sand supply to the intake could be cut off by unexpected sand build-up) the installation of a series of fixed units could be considered on the **outside** of the plant to ensure continuous water flow to the intake structure. When jet pumps are considered to be installed inside an intake the jet pump should be installed at the bottom of a conically shaped floor for more effective extraction of sediment (refer to Appendix B for an illustrative example).

vii) Effluent from dredged sediments should be discharged back into the river under controlled conditions to satisfy the legal requirements pertaining to effluent discharged into rivers. One appropriate manner of dealing with the effluent would be to discharge the dredged sediment into a containment dam (which could be formed by earth or sand levees) with a properly designed overflow weir which could be adjustable to enable the decanting (overflow of upper layer of cleaner effluent water column) of water from the pond to minimise the concentration of solids discharged into the river. The Environmental Impact Assessment (EIA) Procedure (refer Chapter 8) must be followed in all cases where sediment is removed and discharged into a river.

viii) Consideration should be given to the utilisation (selling) of coarser dredged sediments (suitable for building purposes). The income could be used to offset operation costs. This implies sand mining from a river and requires a permit as prescribed by the Minerals Act (Act 50 of 1991).

10. RECOMMENDATIONS FOR FUTURE RESEARCH

Based on DWAF's scheduled continuation (under contract) for a further two years of sediment removal from sediment-prone intakes, with jet pump systems in the Mpumalanga and the Northern Province, as well as difficulty experienced with the dredging of cohesive sediments, the following two issues are recommended for future research actions :

i) Monitoring and evaluation of DWAF's scheduled work programme with the jet type dredge systems over the next two (2002 and 2003) years in Mpumalanga, Northern Province and elsewhere.
ii) Development of a disintegration nozzle arrangement to increase its effectiveness in the disintegration/fluidisation of silt/clay.

The investigation also revealed the need for training on the effective design of intake structures on rivers. It is therefore also recommended that consideration be given to the transfer of the relevant technology in the effective design of intake structures combined with the appropriate application of the jet-type sediment removal systems at water intakes on sediment laden rivers.

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APPENDIX A: PIPELINE TRANSPORT OF SEDIMENT (P L SLATTER)

APPENDIX A : PIPELINE TRANSPORT OF SEDIMENT

Sediment Characteristics

Particle Size and Particle Size Distribution

The particle size and particle size distribution of the samples tested for this project are presented in Figure A1.

These characteristics are sufficient for characterising the sediment for hydraulic transportation, provided that the sediment forms a settling slurry. If the sediment forms a cohesive slurry, then it will tend to a classical homogeneous non-Newtonian slurry for hydraulic transportation purposes, and rheological characterisation is required, using a vane instrument or similar rheometer.

The principal rheological property defining the erodability and hydraulic transport of a cohesive sediment is the yield stress. The yield stress of a cohesive sediment will depend on many factors, such as the initial solids concentration, time for sediment to build up, degree of consolidation, sedimentation rate, concentration, particle size and size distribution, pH, ionic strength, shear history, and small changes of mineralogy, especially of the clay component. The literature recommends a limit of the yield stress value to 1.5 Pa, to ensure easy erosion and transport (Bednarczyk *et al*, 2000). From tests done on these and similar materials, it is estimated that a yield stress value of 1.5 Pa corresponds to a volumetric concentration of about 4%. Given the wide range of influencing factors mentioned above, the time to reach this state would have to be evaluated on site. However, indications from the literature are that this time could be as little as several hours (Michaels & Bolger 1962).

<u>Transport of Sediment</u>

Non-Cohesive sediments

Flow Characteristics

The flow characteristics of non-cohesive sediments are quite different to those of cohesive non-Newtonian sediment transport. The particles settle rapidly, form a heterogeneous suspension which stratifies in horizontal pipe flow, and the particles are transported principally either as a moving bed or by turbulent suspension. Particle settling under both static and dynamic flow conditions is a major consideration, and could lead to pipe blockage. The determination of the deposition velocity V_{dep} is thus of prime concern, and the pipeline should operate at a mean flow velocity V of at least 0.5 m/s faster than this. There are many correlations for the determination of the design parameters for heterogeneous pipe flow, the simplest of which will be presented here.

Deposition Velocity

The deposition velocity V_{dep} can be determined from the nomogram of Wilson (1979), presented in Figure A2. As long as the pipeline is operated above this velocity (plus a margin of safety), the pipeline should not block.

The operating point of most settling slurry pipelines is based on the suspension velocity, V_{susp}, which is the velocity at which the particles no longer form a moving bed, but are all fully suspended. The correlation proposed by Durand & Condolios (1952) is:-

$$V_{susp} = F_L \sqrt{2gD(S_s - S_w)}.$$

The modified Froude number F_L is a function of the particle size and the solids concentration as shown in Figure A3.

The horizontal pipe flow wall shear stress for a heterogeneous slurry can be determined from the modified Durand (1953) correlation:-

$$\hat{o}_0 = \left(S_m \,.\, \hat{o}_{0w}\right).\left[1 + 85C_v\left(\frac{gD\left(S_s - S_w\right)}{V^2\sqrt{C_D}}\right)^{3/2}\right].$$

The drag coefficient C_D is determined from the settling characteristics of the particles and the wall shear stress for water only $\hat{o}_{0w}$ is calculated from

$$\hat{o}_{0w} = f\,.\frac{\tilde{n}_w\,V^2}{2},$$

and f , the Fanning friction factor for water only, is calculated from the well known Colebrook-White equation (Paterson & Cooke, 2002)using the properties of water only:

$$\frac{1}{\sqrt{f}} = -4\,\log\left[\frac{1.26}{Re\sqrt{f}} + \frac{k}{3.7D}\right],$$

where k is the pipe roughness. Note that the Colebrook-White equation is implicit and must be solved by trial and error.

The results obtained from the various correlations presented in the literature for heterogeneous slurry pipe flow vary considerably for identical conditions, and the following should be borne in mind (Paterson & Cooke, 2002):-

- Correlations should not be used beyond the limits of the data upon which they are based.

- The interpretation of deposition and suspension velocity, and the selection of a representative particle size are subjective and are usually based on experience.

- For sediments with a wide particle size distribution, both viscous and settling characteristics can be observed. The transport of such sediments requires a much more complex mechanistic analysis utilising computer based numerical algorithms.

Cohesive sediments

Flow Characteristics

The flow characteristic of a cohesive sediment is principally that of modifying the viscous characteristics of the transporting medium. The particles either do not settle at all, remaining as a colloid with particles suspended by particle interaction, or they settle very slowly. These sediments form a homogeneous suspension which does not stratify, and the particles are transported principally in laminar shear flow or turbulent flow. Pipe blockage is not normally of concern, unless static conditions are allowed to cause a dense deposit to form on the pipe invert.

The viscous characteristics – termed the rheology - of a cohesive sediment slurry are usually much greater than that of water only, and are also non-Newtonian. The rheology of such a slurry is related to the surface chemistry of the particles, and is sensitive to changes in concentration, particle size and size distribution, pH, ionic strength, shear history, and small changes of mineralogy, especially of the clay component.

Rheological characterisation

The rheological characterisation of non-Newtonian slurries has received much attention in the literature and the development of this discipline is ongoing. Although more complex rheological models are available, this section has deliberately targeted a more pragmatic approach, and the simplest model which can accommodate a yield stress has been used. To this end, the Bingham plastic rheological model (Govier & Aziz, 1972) has been found useful by many researchers to approximate the viscous flow behaviour of cohesive non-Newtonian slurries (eg Xu *et al*, 1993). The constitutive equation for pipe flow is given by :-

$$\hat{o} = \hat{o}_y + K\left[-\frac{du}{dr}\right]$$

Laminar flow

The constitutive equation can be integrated twice in the usual manner to produce the velocity profile and the well known Buckingham Equation:-

$$u = \frac{D}{4K\hat{o}_0}\left[\left(\hat{o}_0 - \hat{o}_y\right)^2 - \left(\hat{o} - \hat{o}_y\right)\right]$$

$$V = \frac{D}{2K\hat{o}_0^3}\left(\hat{o}_0 - \hat{o}_y\right)^2\left[\frac{\left(\hat{o}_0 - \hat{o}_y\right)^2}{4} + \frac{2\hat{o}_y\left(\hat{o}_0 - \hat{o}_y\right)^2}{3} + \frac{\hat{o}_y^2}{2}\right]$$

Dimensional analysis of the Bingham plastic model as applied to circular pipe flow will yield three dimensionless groups. Besides the standard friction factor, the other two dimensionless groups are of prime concern here. They are the Reynolds number and the Hedström number:-

$$Re = \frac{\rho VD}{K} \quad \text{and} \quad Re\,c = \frac{\rho VcD}{K}$$

$$He = \frac{D^2 \rho \tau_y}{K^2}$$

Transitional Flow

Slatter & Wasp (2000) proposed three correlations for the laminar/turbulent transition of a Bingham plastic fluid, which covers the full range of Hedstrõm numbers.

<u>Low range – correlation 1.</u> The low range correlation has been formulated as

$Rec = 2100 \text{ for } \quad He < 1.7x10^{3}$ This results in a critical velocity which can be calculated directly from

$$Vc = \frac{2100K}{ñD}.$$

<u>Intermediate Range– correlation 2.</u> The intermediate range correlation is formulated as

$$Rec = 155\, He^{0.35} \quad \text{for } 1.7x10^{3} < He < 1.5x10^{5}$$

This results in a critical velocity which can be calculated directly from

$$Vc = \frac{155ô_y^{0.35}K^{0.3}}{ñ^{0.65}D^{0.3}}.$$

<u>High Range– correlation 3</u>. The high range correlation has been formulated as

$$Rec = 26\, He^{0.5} \quad \text{for } He > 1.5x10^{5}$$

This results in a critical velocity which can be calculated directly from

$$Vc = 26\sqrt{\frac{ô_y}{ñ}}.$$

Turbulent Flow

Analysis of the turbulent flow of non-Newtonian fluids (Slatter 1994, 1995) has been found to depend on the representative particle size of the slurry, d_x. The roughness Reynolds number is used in order to determine whether smooth wall turbulent flow or fully developed rough wall turbulent flow exists.

$$Re_r = \frac{8\, ñ\, V_*^{2}}{ô_y + K\left[\frac{8\, V_*}{d_x}\right]}.$$

where V_* is the classical shear velocity $V_* = \sqrt{\frac{ô_0}{ñ}}$ and d_x is the representative particle size.

If $Re_r < 3{,}32$ then smooth wall turbulent flow exists and the mean velocity is given by:

$$\therefore \frac{V}{V_*} = 2.5 \ln\left(\frac{R}{d_x}\right) + 2.5 \ln Re_r + 1.75 .$$

If $Re_r > 3{,}32$ then fully developed rough wall turbulent flow exists and the mean velocity is given by

$$\frac{V}{V_*} = 2.5 \ln\left(\frac{R}{d_x}\right) + 4.75 ,$$

and the friction factor is constant.

Pump/System Curves

Once the relationship between pipe velocity and wall shear stress has been determined by the above procedures, the system curve can be plotted. The system curve is the relationship between the hydraulic head required to operate the pipe line and the corresponding volumetric flow rate. The pipe frictional head loss can be calculated from the wall shear stress by

$$H = \frac{4\hat{o}_0 L}{\tilde{n} D g}$$

Once the system head characteristic has been established, it can be applied to the pump characteristic, and the operating point is obtained at the intersection.
The pump characteristic should be derated for solids handing as per the suppliers specification.

NOMENCLATURE

Symbol	Description	Unit
A	cross sectional area	m^2
C	concentration	
C_D	particle drag coefficient	
d	particle diameter	µm
D	internal pipe diameter	m
f	Fanning friction factor	
F_L	modified Froude number	
H	hydraulic head	
He	Hedström number	
k	pipe roughness	m
K	fluid consistency index	Pa s^n
L	pipe length	m
n	flow behaviour index	
p	pressure	Pa
Q	volumetric flow rate of slurry	m^3/s
r	radius at a point in the pipe	m
R	radius of the pipe	m
Re	Reynolds number	
S	relative density	
u	point velocity	m/s
V	average slurry velocity	m/s
V_*	shear velocity	m/s
	increment	
µ	dynamic viscosity	Pa s
ñ	slurry or fluid density	kg/m^3
ô	shear stress	Pa
ô$_y$	yield stress	Pa

Subscripts

0	at the pipe wall	
85	85^{th} percentile of the particles passing	
c	critical, transitional	
obs	observed (experimental)	
r	roughness	
s	solids	
susp	solid suspension limit	
v	volumetric	
w	water	
x	representative	

FIGURES

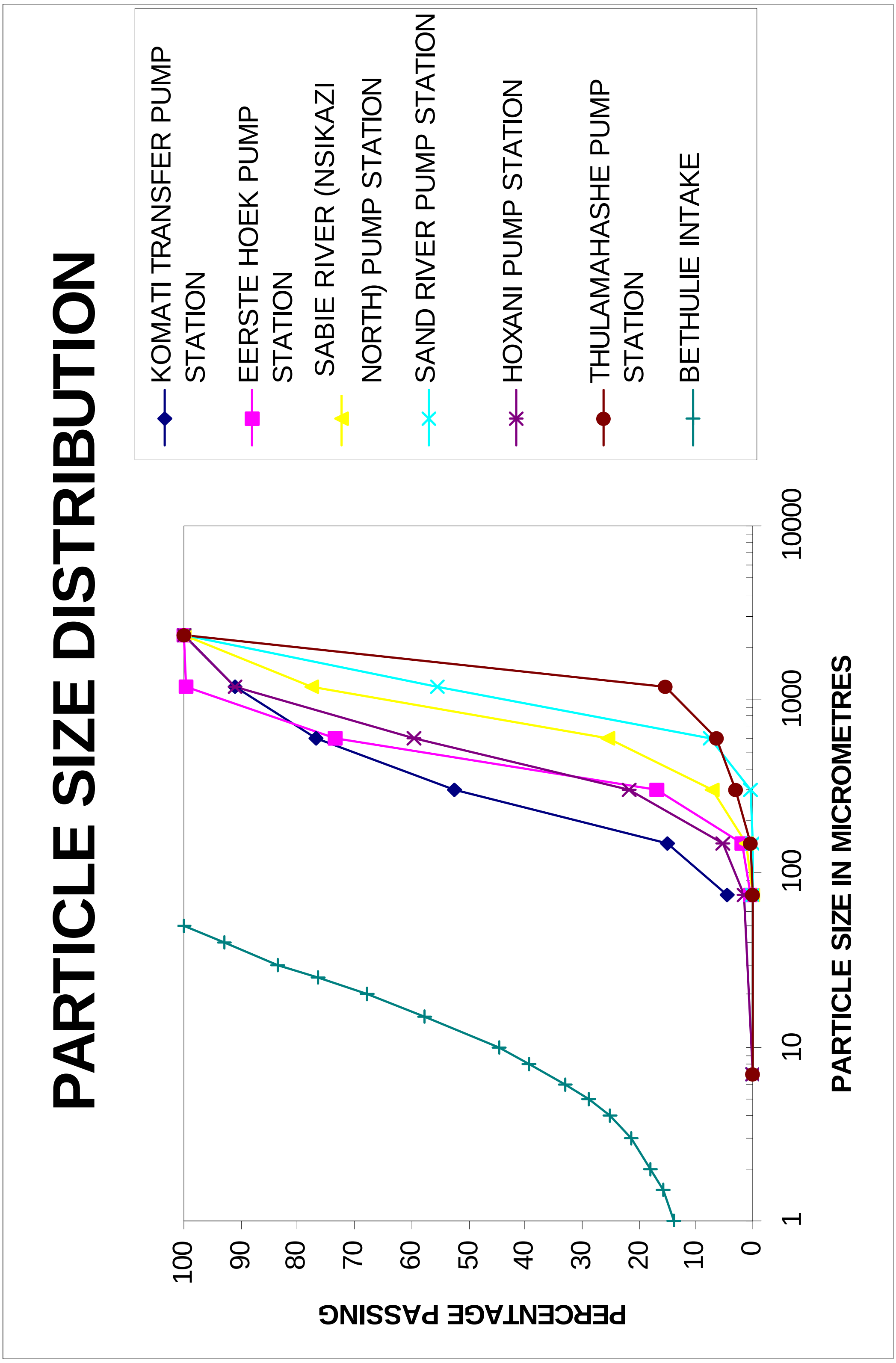

Figure A1 : Particle size distribution of river sediment sampled at the sediment prone water intakes included in this investigation.

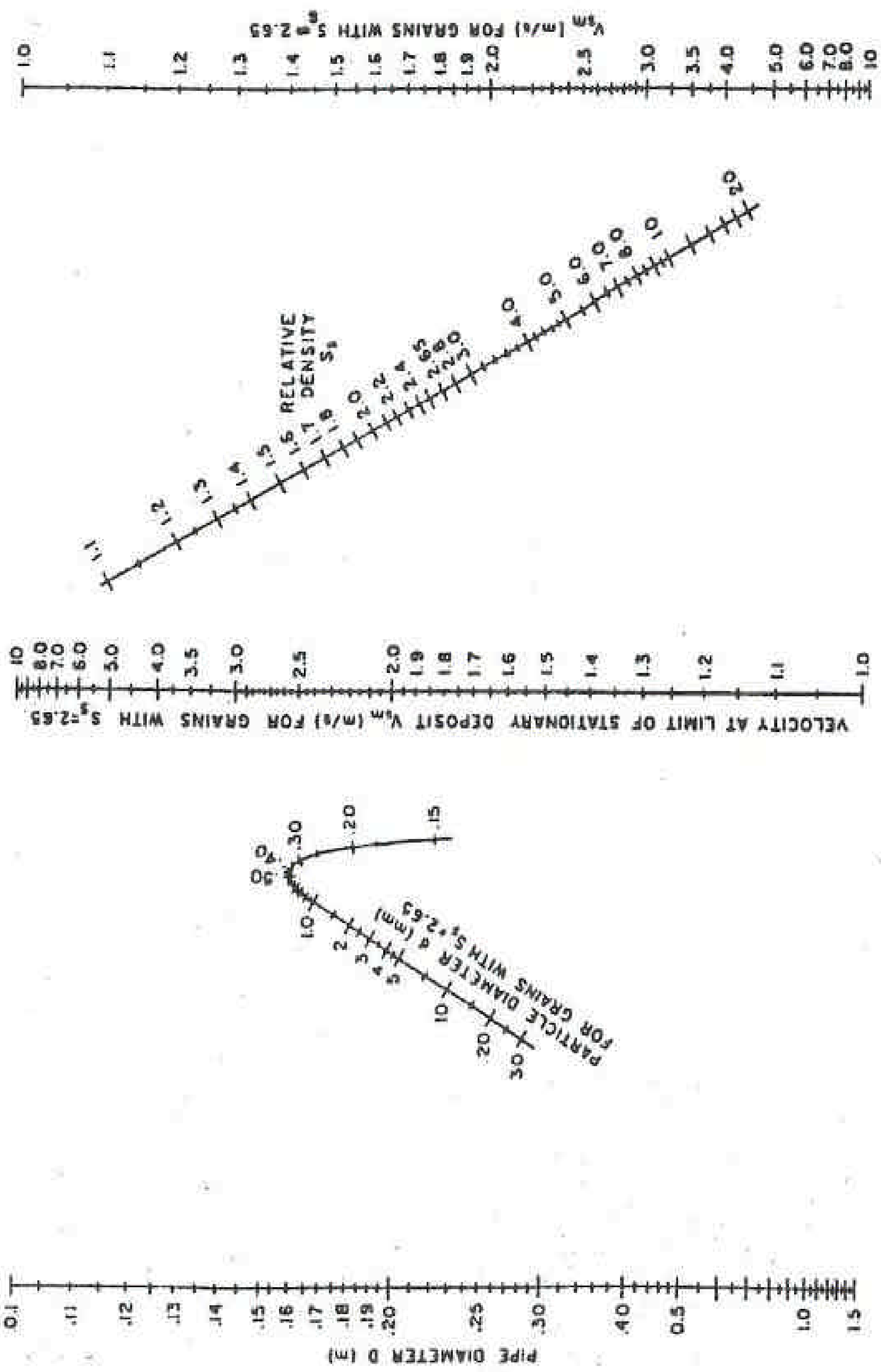

Figure A2 : Nomogram of Wilson (1979)

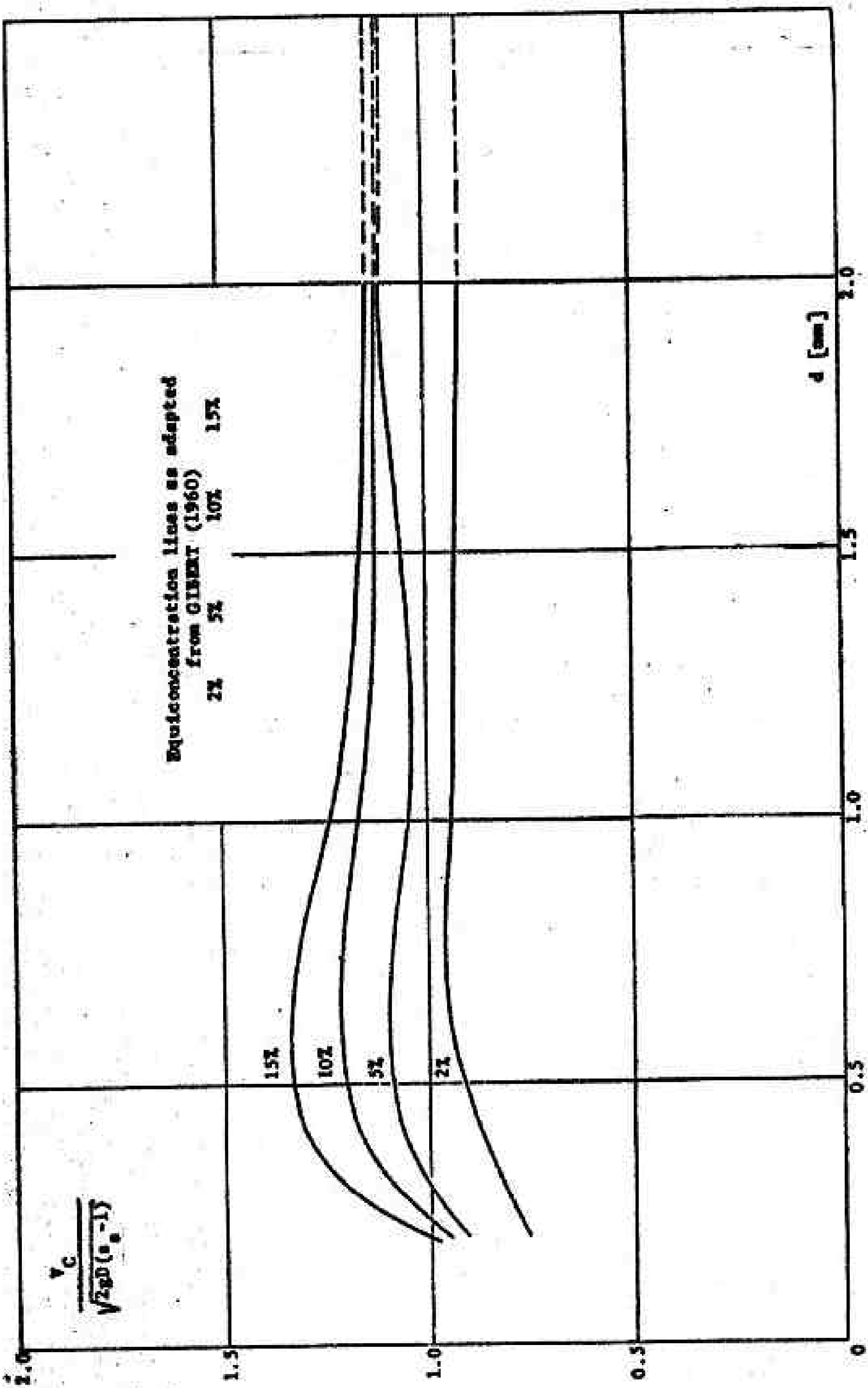

Figure A3 : Modified Froude number F_L vs particle diameter with concentration as variable

Examples

In this section, an example of each type of flow is presented.

Non-Cohesive sediments

For this example the requirement is to construct the pumping system curve for a non-cohesive sediment with the following properties, flowing in a 100mm diameter steel pipe (k = 45 ìm) which 100m long and with a horizontal profile:-

Sediment Relative Density	Ss	2.65	
Volumetric Concentration	Cv	5.00% - 30%	
Representative Particle Size	d	1	mm

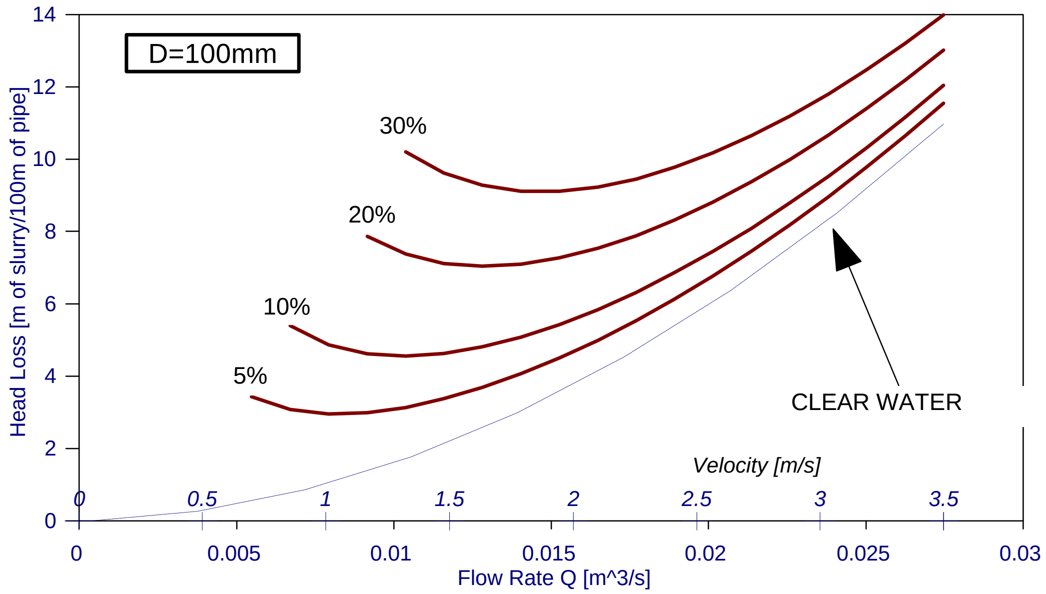

Figure A4 : Pumping system curve for a non-cohesive sediment

Cohesive sediments

For this example the requirement is to construct the pumping system curve for a non-cohesive sediment with the following properties, flowing in a 100mm diameter steel pipe (k = 45 ìm) which 100m long and with a horizontal profile:-

Volumetric Concentration	Yield Stress	Fluid Consistency Index	Slurry Density
Cv	Ty	K	Sm
%	Pa	Pa.s	
2	0.58	0.0010	1.033
4	1.41	0.0054	1.066
6	3.19	0.0155	1.099
8	6.49	0.0282	1.132

Solids Relative Density S_s = 2.65 and Representative Particle Size d_x = 45 ìm.

(A lower range of concentrations has been chosen, because cohesive sediments require considerable pumping heads to pump at higher concentrations.)

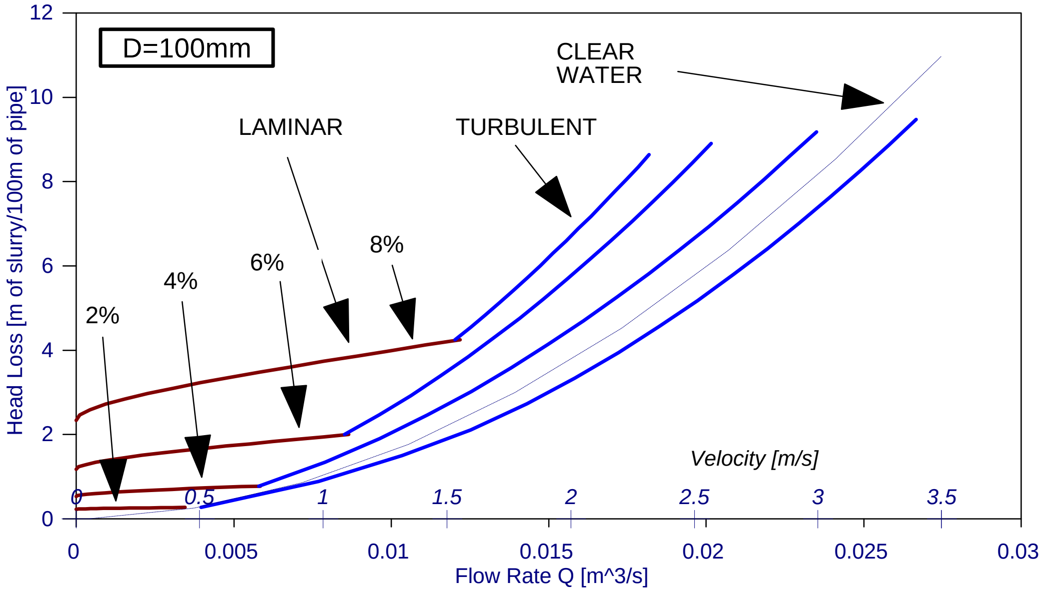

Figure A5 : Pumping system curve for a cohesive sediment

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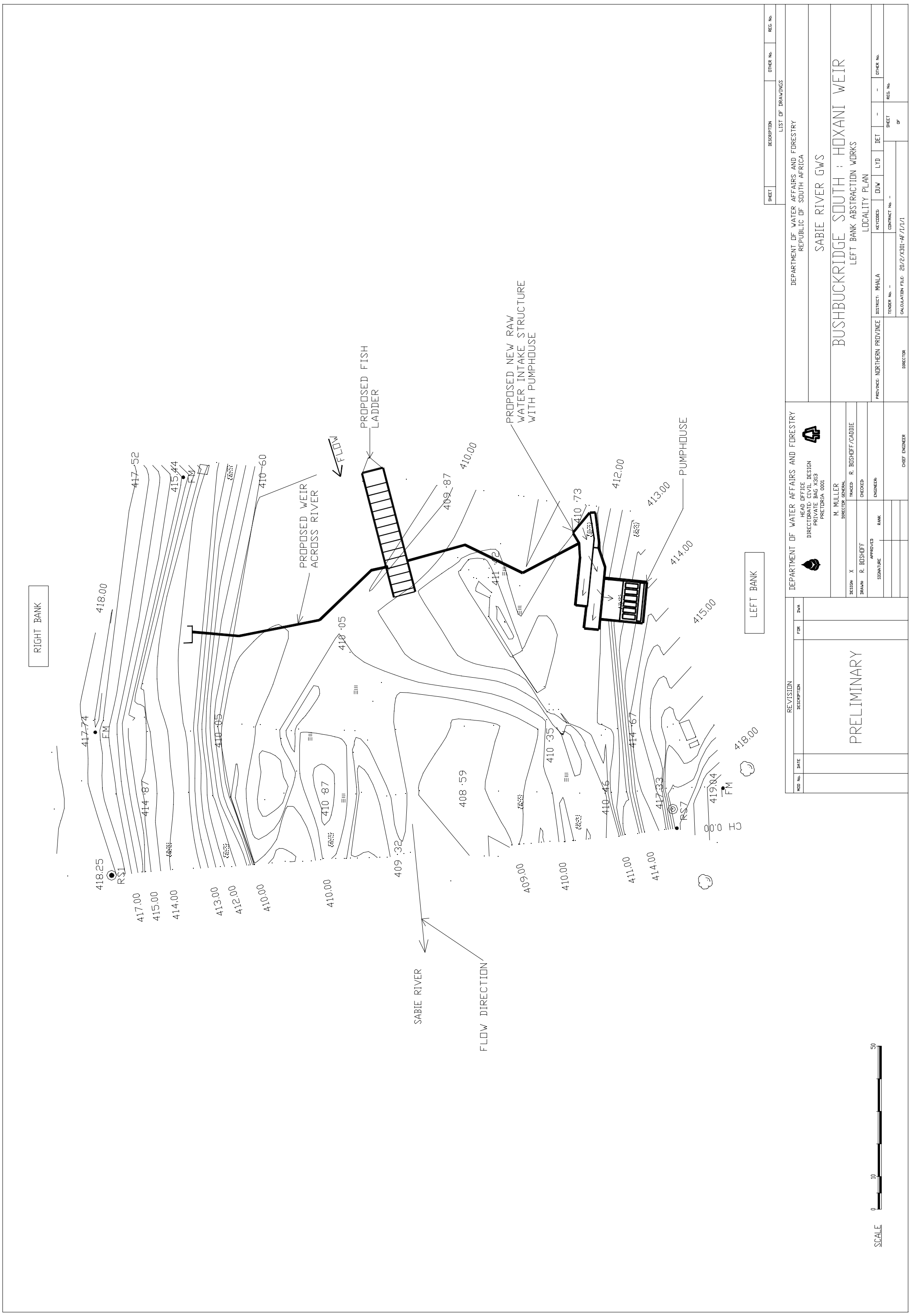
APPENDIX B : EXAMPLE OF AN EFFECTIVE DWAF DESIGN OF THE HOXANI WATER INTAKE STRUCTURE ON THE SABIE RIVER WITH AN APPROPRIATE INSTALLATION OF A JET-TYPE PUMP SEDIMENT REMOVAL SYSTEM

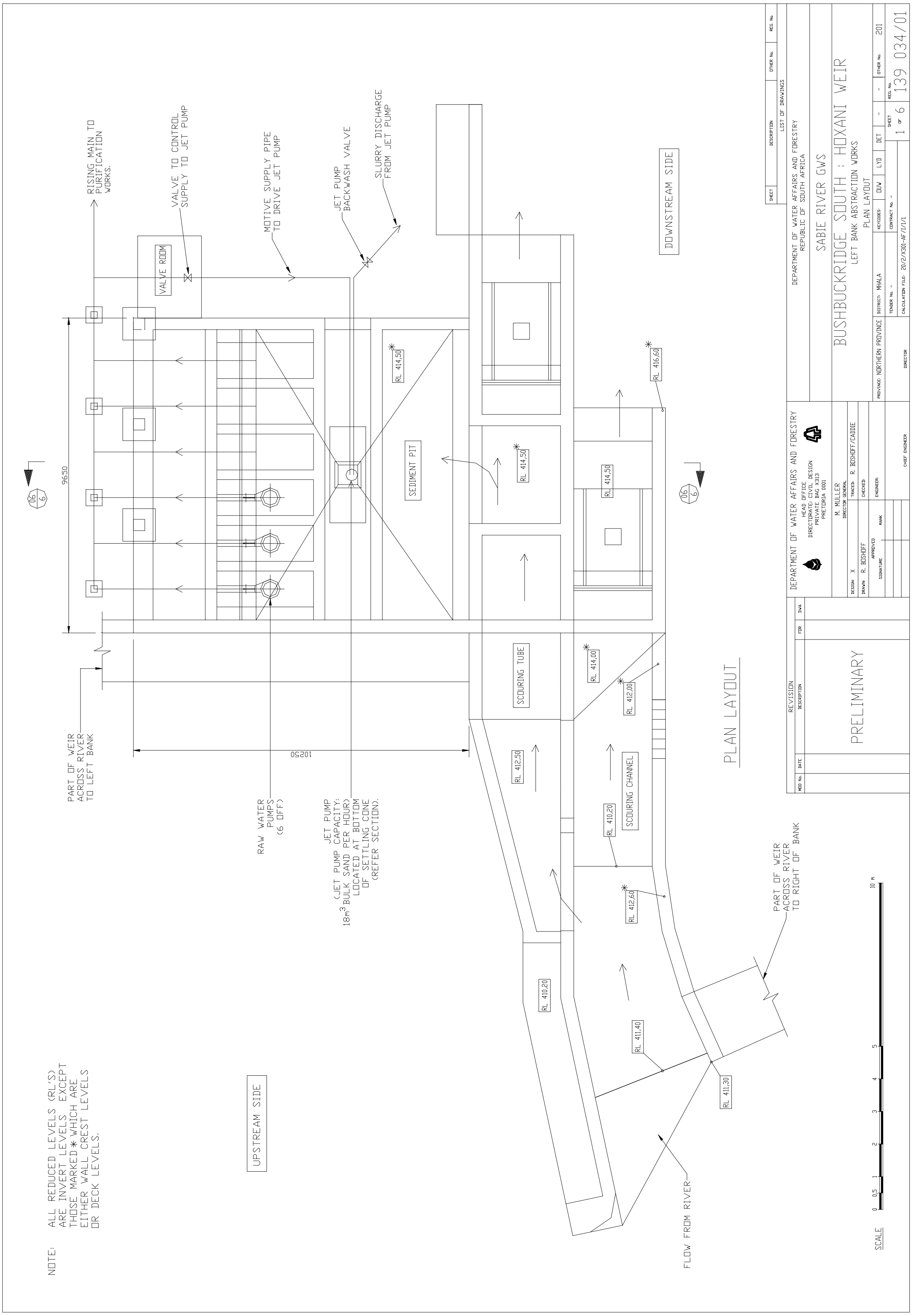
[PUBLISHED WITH PERMISSION OF DWAF]

Three reduced drawings :

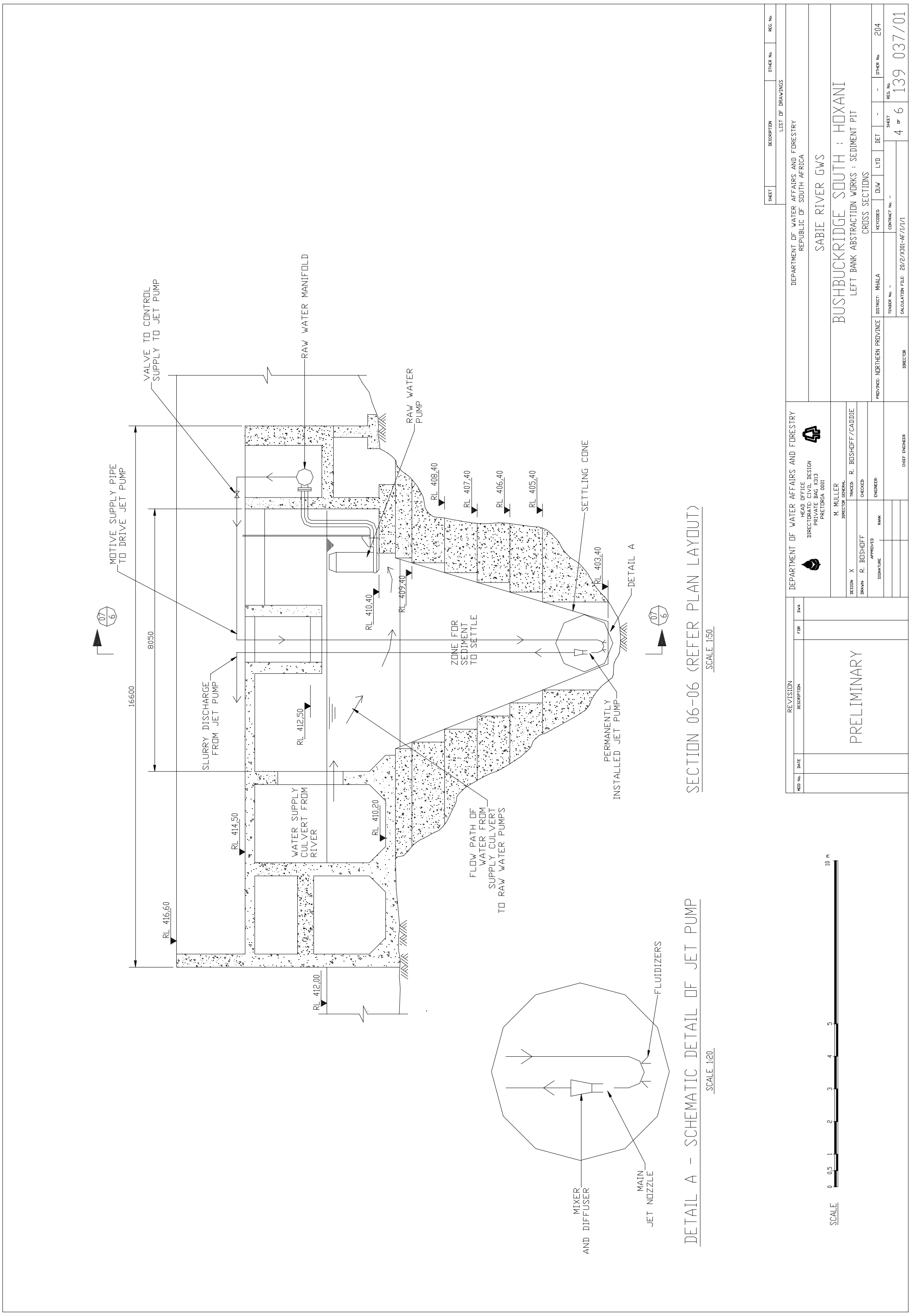
i) Locality Plan (page B2)
ii) Plan layout of Intake Structure (page B3)
iii) Cross section of Intake Structure (page B4)



Hoxani Intake : Layout



Hoxani Intake : Plan



Hoxani Intake : Cross-Section