A method for evaluating the economic benefit of sediment control in irrigation systems

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(TDR Project R5840)

Report OD/TN 81
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Summary

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Problems of sedimentation in run of river irrigation systems can be reduced or eliminated by constructing sediment control structures. These reduce the quantities of sediment entering irrigation systems by excluding sediment at river intakes, or extracting it from canal flows.

The first section of the report summarises a method for evaluating the economic benefits of sediment control. The method is based on conventional cost benefit calculations, incorporating in the "without project" scenario the estimated costs of the future loss of productive potential due to sedimentation. "With project" costs are calculated on the basis that sustaining an acceptable irrigation service to the scheduled area, and preventing future reductions in that area, are primary objectives. The impact of improved sediment control on the financial viability of irrigation agencies forms part of the assessment.

The second section of the report describes a verification of the evaluation procedure at the Agno River Irrigation System, (ARIS) in the Philippines. The system had a history of severe sedimentation problems, and a rapidly declining irrigation service area. Low cost sediment control structures, designed using the methods developed at HR Wallingford, were constructed in 1990. Predictions of the economic and technical impact of the structures on the performance of system were made in 1991, (Reference 1). Actual performance was then monitored using technical and economic data collected between 1991 and 1993. Although the operation of sediment extractors was affected by an earthquake, and the failure of a mine tailings dam in the catchment, the results confirmed the earlier predictions.

The economic returns resulting from operation of the sediment extractor were positive, even for the most pessimistic scenarios. A very large Internal Rate of Return (IRR), in excess of 100%, is predicted on the basis of measured performance and reasonable assumptions concerning the future operation of the extractors. The financial viability of the system, (as defined by the irrigation agency), has been improved, with the system achieving viability in 1993 for the first time in many years. More effective sediment control has halted and reversed a long term decline in the area irrigated.

More generally it is concluded that combining a sediment extractor which continuously abstracts water and sediment from a main canal, with an intermittently flushed small settling basin, provides a flexible and economical means of sediment control. In many cases such low cost sediment control structures will pay for themselves in a few years through reductions in desilting costs. If improved sediment control enables a larger area to be irrigated very large internal rates of return will be achieved.

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1. INTRODUCTION

1.1 Sedimentation problems in irrigation canals

Maintenance budgets in many run-of-river irrigation schemes are dominated by the costs of removing sediment from canals. The problem results from the limited sediment transporting capacity of most canal networks, and occurs when water is diverted from rivers carrying high sediment loads. Sediment deposition results in rising canal bed levels, reduced canal capacities, and problems in supplying the required amounts of water to some or all parts of the irrigated area.

Sediment deposits have to be removed to maintain irrigation supplies, and while this is an acceptable part of maintenance in schemes with a small sediment input, desilting costs become excessive when large quantities of sediment settle in canals. Operating authorities often have restricted maintenance budgets and can only afford to remove a proportion of the sediment settling in canals each year. The area that can be irrigated then reduces as sediment deposits build up. A reduced discharge capacity leads to an unreliable and inequitable water supply in the downstream parts of systems, recognised as significant determinants of poor co-operation between farmers and irrigation agencies. Irrigation systems with sediment problems typically achieve a low irrigation service fee recovery, and hence a further reduction in the resources available for maintenance. Eventually these systems deteriorate, until either they are rehabilitated, or they reach a point where effective irrigation over large areas becomes impossible.

The options for reducing sediment loads entering and settling in irrigation systems include:

- Improved catchment management to reduce the sediment loads supplied to rivers.
- Sediment detention structures such as check dams or small reservoirs constructed in a catchment to trap sediment before it enters a main river system.
- Sediment exclusion structures located at the entrance to canal networks, or extraction structures located within canal networks.

While improved catchment management has many "on site" benefits, a significant reduction in the sediment loads supplied to rivers following the introduction of improved soil conservation may not be achieved for decades in medium and large catchments. Construction of sediment detention structures or small reservoirs would not normally be justifiable solely to reduce sedimentation problems in downstream run of river irrigation projects. Reservoirs do have a substantial impact on the quantities of sediment passed to downstream rivers, but evidence from the USA and elsewhere suggests that reductions in downstream sediment loads are far smaller than one might expect (Reference 2).

In most cases a low cost solution to sedimentation problems in irrigation systems is needed, that provides a rapid reduction in the rates that sediment settles in canals. Improved sediment control at the irrigation system location is usually the only means of achieving this. This might consist of reducing the diversion of sediments from a river by modifications to the irrigation intake, (sediment exclusion), introducing sediment trapping structures such as a settling basin or sediment extractor in the main canal, (sediment extraction), improved canal operational practises that minimise entry of sediments or opportunities for sediment deposition, or improving the methods used to remove sediments from silted canals, (desilting). A sediment management strategy at a particular scheme might include several or all of these elements.

It is usually more cost effective to reduce the concentrations and size range of sediments entering canals with a sediment control structure than to rely on canal desilting, which can rarely be carried out sufficiently fast to prevent at least temporary losses in canal capacities.

Sediment control has two major benefits. Firstly, it reduces the amount of desilting required, and hence the costs of sediment removal, and secondly it improves the reliability of water supply to downstream parts of irrigation systems, enabling the irrigated area to be maintained. This has a positive impact on farm income, farm investment, productive capacity, and the long term success of the irrigation scheme. The scale of these benefits is affected by non-engineering parameters such as price structures, market structures, and agricultural policies.

1.2 Economic assessment of benefits of sediment control

The study has developed and applied a method of evaluating the economic benefits of sediment control measures, utilising data that is typically available in developing countries.

The method was outlined in an earlier report, (Reference 1). It uses conventional cost benefit calculations, incorporating in the "without project" scenario the estimated costs of the future loss of productive potential due to sedimentation. "With project" costs are calculated on the basis that sustaining an acceptable irrigation service to the scheduled area, and reducing desilting costs are primary objectives.

The earlier report presented an application of the evaluation procedure at the Agno River Irrigation System, (ARIS), in the Philippines, using pessimistic assumptions for costs and the useful life of an extractor, and was based on a cost level which would be incurred to maintain the full scheduled irrigation area with and without the introduction of sediment control structures. This suggested an Internal Rate of Return (IRR) of just over 60% from introducing sediment control.

1.3 This study

This report summarises the economic evaluation procedure presented earlier, and updates the economic evaluation at ARIS in the light of technical and economic data collected between 1991 and 1993, following the introduction of sediment control facilities at the head of the canal network. Technical and economic monitoring has enabled the predictions made during earlier study to be tested. However the initial period of operation of the new facilities was one in which the effects of an earthquake, and the failure of a mine tailings dam in the catchment, affected the performance of the irrigation system. It is also too short for the longer term impacts of the introduction of sediment control facilities to be demonstrated. Nevertheless the results have confirmed the large benefits provided by the introduction of sediment control in an irrigation system with a history of severe sedimentation problems, and a rapidly declining service area.

A summary of the economic evaluation procedure is presented in Chapter 2, the sediment problem at ARIS, the design of sediment control structures and their measured technical performance is described in Chapter 3. Chapter 4 presents the results of the economic evaluation, which are discussed in Chapter 5.

Conclusions specific to ARIS, and more generally are summarised in Chapter 6.

2. A METHOD FOR EVALUATING THE ECONOMIC BENEFIT OF SEDIMENT CONTROL

2.1 Data sources

Both technical and economic data are needed. Estimating and budgeting of costs and benefits is carried out as far as is feasible using existing data. Much of the information needed will be available from irrigation agency files and in regional and national statistics, however in some cases it will be necessary to carry out local surveys to collect information on gross margins etc.

The data needed to quantify the scale of existing sediment deposition may not be available. It may be possible to distil information from historical maintenance data, bed level surveys carried out for desilting etc, or new surveys may have to be commissioned to obtain reliable information. Without measurement of sediment volumes from reliable surveys, ideally supplemented by measurements of sediment inflows, the validity of estimates of the annual volumes of sediment deposition will be questionable.

2.2 Selection of sediment management strategies

Once satisfactory estimates have been acquired then technical expertise is needed to select one or more sediment control options to be compared with the "without project" scenario. It will be necessary to make quantitative predictions of the performance of a range of sediment control options, so as to provide estimates of annual or seasonal sediment balances in the canal system. Additional information will be needed, such as constraints imposed by availability of land, of plant, or of construction skills and materials. Where these constraints can be removed at a price then comparison of the cost of the remaining possible strategies is a next step in the selection process.

2.3 Comparison of costs

In order to compare the costs of different strategies it is necessary to define a common objective which the strategies being compared must satisfy. In the case of irrigation schemes it would be necessary to stipulate a minimum acceptable water delivery or service area to be satisfactorily supplied over a defined period. This would normally be the water supply and service area assumed when the system was designed. Lower targets may be more realistic in systems where sediment problems have been particularly severe, or the original design assumptions are no longer valid. The main point being that the objective is a common one.

The information needed in order to compare costs will be:

- The capital cost of sediment control structures. This should include any land acquisition costs or any compensation costs incurred.
- The costs of initial desilting required to return the canal system to its design condition.
- The annual cost of maintenance. This should include the cost of maintaining the structures and any further costs required to fulfil the stated objective, such as removal of remaining sediment.
- The expected life of the structures. This should be based on realistic assessment of the quality of construction and materials and the expected operational circumstances.
- The current opportunity cost of capital. This will vary from country to country, and may be affected by the type of project and the funding source.

Once these values have been established a present value for the cost of each alternative strategy considered, including a no intervention or "without project" case, can be calculated using the formula

Present value of costs (NPV) $= C + \dfrac{M \times (1+r)^n - 1}{r(1+r)^n}$

where:

C is the capital cost of the sediment control structures and other start up costs such as initial scheme desilting.

M is the annual maintenance required

r is the accounting rate of interest

n is the expected life of the structures

A selection can then be made on the basis of least cost for equal end service.

2.4 Valuation of social and environmental costs

In most cases where a sediment control strategy is under consideration a situation of uncertainty and inequity already exists within a scheme. It is therefore important to consider to what extent it is possible to quantify any observed social and environmental impacts. Although it is not feasible to find money values for all impacts, particularly those which are regarded as aesthetic, the more impacts that can be evaluated the more valid a cost benefit calculation becomes. Use of an environmental check list (Reference 3) is a useful first step in identifying significant impacts.

The following list is by no means exhaustive, but indicates the factors which should be considered:

- Loss of land for construction of sediment control structures
- Change in sediment disposal regime
- Change in water volumes and flow rates
- Equity of water delivery
- Fertility and or yield
- Cropped area
- Cropping pattern
- Inputs
- Product prices
- Farmer participation and co-operation
- Management

Data is probably available on existing schemes for many of the parameters listed, and it may be helpful to calculate historic trends. Information on the remaining items can be collected in a rapid appraisal. Some items will not lend themselves to monetary valuation, but may be assessed through use of indicators, for example rates of irrigation fee recovery could be used as an indicator of farmer co-operation.

Impacts should be sorted in terms of:

a) whether the impact is quantifiable

b) whether the impact is of sufficient significance to require quantification

c) whether the impact falls to the cost or to the benefit side of the calculation

It will then be possible to proceed with a cost benefit calculation.

2.5 Cost benefit analysis

The usual approach to cost benefit analysis is applied, (Reference 4). The distinguishing feature of the procedure recommended here is to extend the breadth of the analysis as far as is possible without making the process either too costly, or unwieldy. It is hoped that the increased breadth will produce a figure for the net present value of the intervention or an internal rate of return which, alongside the qualifying information gathered, will accurately reflect the long term impacts.

There are of course problems involved in reconciling conventional discounting procedures with the objectives of sustainable development and environmental accounting (References 5 and 6). The practice of discounting has the effect of making future investments comparatively cheaper than those made at the outset of a project. The Internal Rate of Return will be better for a scheme where the capital investment is spread over a number of years than for one where the same capital is invested in year one, as is the case when sediment control structures are constructed. These factors are discussed further in Reference 1.

2.6 Financial viability

The costs of implementing improved sediment control are usually met by an irrigation agency, while the benefits accrue both to the agency and to individual farmers. An evaluation of the impact of improved sediment control on the financial viability of the agency is required as part of an economic assessment. The principal benefits of improved sediment control to an agency will be a reduction in maintenance costs, through reduced desilting. If improved sediment control results in improved reliability of irrigation, or an expansion in the irrigated area then the agency may also benefit from increased revenue from irrigation service fees. Institutional and practical arrangements for improving fee recovery should therefore form part of the project design.

3. DESIGN AND OPERATION OF THE SEDIMENT CONTROL FACILITIES

3.1 Sedimentation in the Agno River Irrigation System

The system is supplied from the Agno River, Luzon, (Figure 1). The catchment area is approximately 39,000 km^2, of which 90% is officially classified as forest. About half of the catchment is in reality now open grassland, much being used for cattle grazing, and subject to seasonal uncontrolled burning. The higher areas of the catchment are characterised by steep slopes, and geologically young rocks which weather and fracture readily (References 7 and 8). The area is also subject to earthquakes which trigger landslides and ensure a massive supply of easily erodible sediments.

The annual rainfall of around 3,600 mm occurs mostly in the six months from July till the end of December. High rainfall intensities in storms and typhoons result in high rates of soil erosion from the unprotected parts of the catchment. The upper reaches of the river pass through the Bagio Mining District, where up to 30,000 tons of mine tailings are produced every day. Substantial quantities of tailings are supplied to the river, through overtopping and occasional failures of mine tailing dams.

Pollution caused by mine tailings had long been recognised as a problem by the farmers in the lower plain areas, identified in the early 1960's as the cause of problems in reservoirs, canals and on the fields, (Reference 9). A catastrophic failure of the Philex Mining Corporation's Tailings dam in January 1992 resulted in a massive injection of mine tailings into the river system, which blocked the Agno Irrigation offtake and main canal, halting irrigation.

The Agno system was constructed in the 1950's with an original design service area of 18000 ha, later reduced to 11500 ha as a result of supply difficulties and to account for the high water duty for parts of the scheme with sandy soils. Water is diverted to a 38 m^3/s (original) design capacity main canal from a conventionally designed river intake located at the outside of a bend on the Agno River. The intake consists of a raised weir, and gated sluice channel, and a gated canal intake supplying 6 intake barrels that run under the river embankment to the head to the main canal. (See Figure 2). The first kilometre of the main canal is lined, the rest of the system consisting of earthern canals. The layout of the main and lateral canals is indicated in Figure 3. Effective irrigation has been confined to the head reach and parts of the middle reach zones in recent years.

Figure 4 shows the decline in the ARIS wet season service area since 1985, mostly attributed to the effects of sediment deposition in the canal system. (As wet season flows in Agno River are very much larger than the irrigation requirement, the area that can be irrigated in the wet season is controlled by the discharge capacity of the canal system.) The graph shows a steady decline in wet season area to 1987, followed by a dramatic reduction resulting from an earthquake and operational problems at the headworks. Large scale desilting works carried out under the World Bank funded Irrigation Operation Support Programme (IOSP) programme in 1989/90, did increase the irrigated area, but to much less than the IOSP target area of 11500 ha., and failed to halt the ongoing decline in wet season service area.

Faced with a declining service area, high desilting costs, and low fee collection, the National Irrigation Administration (NIA), collaborated with HR Wallingford in a study to investigate sediment exclusion options at Agno. Following the study NIA constructed improved sediment handling facilities in 1991, with funds provided through USAID. These were intended to provide a relatively low cost, medium term, partial solution to the existing sediment problem, to cover the period in which decisions concerning the construction of the San Roque Dam were to be made. The effect that the improved sediment handling facilities had on the wet season areas that could be irrigated is shown in Figure 4.

3.2 Improved sediment management facilities.

The assumptions and reasoning which led to the design of the sediment control facilities for the Agno River Irrigation System are described in Reference 11. Here a brief account of the design is given.

Sediment control facilities consist of a vortex tube sediment extractor and low level sluicing gates located in the main canal, both discharging into an escape channel which conveys the extracted flow and sediments back to the Agno River, see Figure 2. Vortex tubes operate by continuously extracting the bottom layer of the flow from the canal, which carries the majority of coarser sediments. For simplicity, the combined sediment extraction facilities are termed the "sediment extractor".

The facilities were designed to extract sands and coarser material from the canal. Finer material causes conveyance problems in the smaller canals of the system, which have a lower capacity to transport sediments. Construction of small settling basins at the heads of the lateral canals was also recommended, (Reference 11), to trap finer sediments. The basins were to be desilted using machines, but were not constructed during the period covered by the study.

The anticipated operation of the structures, the problems encountered in 1992, and the revised system of operation instituted in 1993 are described in Appendix 2.

3.3 Sediment monitoring

Sediment monitoring was undertaken to quantify the effect of the sediment extractor on the sediment loads passing downstream in 1992 and 1993. A description of the measurements carried out and the results obtained is presented in Appendix 2.

Data from 1993 was used to quantify the performance of the extractor, due to the difficulties which affected the vortex tube operation in 1992. Two key aspects of the results are presented in this section, the performance of the sediment extractor, and sediment balances for the Agno RIS with and without the extractor operating.

The performance of a sediment extractor can be described by a sediment trapping efficiency, TE, defined as:

$$TE = \frac{\text{Sediment quantity extracted}}{\text{Sediment quantity entering canal}} * 100\%$$

As the extractor was designed to reduce the quantity of sediments in the sand size range entering the irrigation system, its trapping efficiency is calculated for sand loads, that is sediments larger than 63 microns. The overall sediment trapping efficiency for the 1993 wet season was 56%. (When the sand load diverted from the main canal by the extractor, but subsequently passed to Lateral A Extra, and entering the irrigation system is accounted for, the trapping efficiency reduced to 52%). As the extractor is most efficient at diverting larger sediments, it reduces the sizes in the sediment mixture passed to the canal network. Smaller sediments are more easily transported, and less likely to settle in the canal system. Thus the effect of the extractor in reducing sediment deposition in the main canal network is larger than might be expected from a trapping efficiency of 52%.

Sediment balances derived from the data measured in the 1993 irrigation seasons are presented in Figures 5 and 6. Separate balances have been derived for conditions with and without the sediment extractor. (The assumptions used to make these calculations are explained in Appendix 2.) The quantities of greatest interest are the annual sediment volumes predicted to be depositing in the canals of the irrigation system, 23,200m^3 with the sediment extractor, and 39,750m^3 without the extractor.

4. ECONOMIC ANALYSIS

4.1 Data used

NIA management data

Economic and other data used in the analysis is summarised in the tables forming Appendix 1. Data from 1992, which was very atypical due to the impact of the mine tailings dam failure on the operation of the scheme, has not generally been used in the analysis.

NIA have a comprehensive record of the performance of the irrigation system as this is a requirement for billing. The information available from this source was supplemented by a short questionnaire applied to a sample of farmers. The farmers were selected from along laterals which had been chosen to represent conditions in the head, middle and tail reaches. This data was collected for HR Wallingford by local NIA staff.

NIA made available data on desilting volumes and costs. Staff numbers and ARIS salary expenditure have also been used to help build a picture of the changes in running costs at ARIS in the period under review.

Farmer assessment

Farmers were asked for information on yield and production conditions including a subjective assessment of water delivery in their fields and pollution effects due to mine tailings.

4.2 Results obtained

4.2.1 Costs

The cost of constructing the sediment extractor, escape channel and ancillary works was 4.2 million Pesos.

Costs for desilting the distribution system for the period under investigation have been extracted from NIA records and are included in Table A1.1 in Appendix 1. Expenditure on desilting reduced over the three years to about 1.2 million pesos in 1993, well below the 3 million pesos estimated to be required to maintain the full IOSP wet season target service area of 11,500 ha estimated in Reference 1. Although Irrigator Association (IA) contract desilting costs are increasing, this was more than countered by the fall in machine desilting costs. The unit cost of sediment removal was 20 pesos/cubic metre in the years 1991 - 1993, rather than the 50 pesos assumed in Reference 1. Other factors which influenced desilting costs, which differed significantly from the earlier estimates, are:

- A lower volume of water supplied, due to the reduced wet season service area, table A1.2, when compared with the IOSP wet season target area of 11,500 ha,
- The one off desilting activities supported by Philex mines,
- Increased maintenance activity by the IA's,
- Variations in the sediment concentrations diverted from the Agno River from those assumed initially.

At Agno the main constraint to irrigating larger areas in the wet season is the restriction in canal capacities caused by sediment deposits. In contrast the area that can be irrigated in the dry season is restricted by the amount of water available in the Agno River. Table A1.2 clearly shows an increase in wet season irrigated area between 1991 and 1993, (21%) indicating that the sediment removed by the sediment extractor is reducing the overall desilting task for NIA, to the extent that they are now able to tackle historically accumulated sediment (sediment mining).

This can be illustrated from the information collected for 1993:

Sediment entering the scheme 1993	126,000 m^3
Extracted	45,500 m^3
Settling in canals	23,200 m^3
Unit cost of desilting	20 pesos
Cost	464,000 pesos
Actual desilting expenditure, 1993	836,945 pesos
Approximate volume of historical sediment accumulation removed	18,650 m^3

By "mining" the backlog of historical sediment deposits conveyance capacities in silted areas of the system can be progressively restored, more water can be distributed, and a larger area can be irrigated. Thus, it appears that NIA may benefit from the introduction of improved sediment control both from lower costs, and from increases in income derived from a larger service area. Increased benefitted areas shown in the tables results in higher Irrigation Service Fee (ISF) collections. Apart from the financial benefit to NIA and increases in the number of farmers benefitted, improvement in staff morale and farmer co-operation is apparent.

Table A1.1 (Appendix 1) shows NIA expenditure on Field staff dropping steadily over the period. That benefit is to some extent eroded by the steep rise in office staff costs. However, the rise is less dramatic from 1992 to 1993 than in the previous year. Office staff numbers in fact fell from 20 to 19 over the period but wage bill per person rose in both years, hence the increase in total office wage bill. Overall, however, NIA costs have fallen by 20% in two years with major savings occurring in desilting costs and field staff.

4.2.2 Yields and Farmers Gross Margins

Yield results for sample farmers in 1991 - 1993

Farmers for the sample were selected from laterals representative of each reach. They were selected in groups located in the upper, middle and tail sections of the laterals. Results obtained in 1991 and 1993 are given in table form in Appendix 1. In most cases the yield is better in the middle section of the lateral, although there is no direct evidence to suggest that this can be attributed to the farmer's theory that mine tailing pollutants in the water settle out higher up the lateral. Explanations for these yield variations may emerge from further investigation of the volumes of water supplied and from an analysis of inputs.

In the 1991 wet season, middle reach farmers spent heavily on inputs. In the wet season of 1993 this was again the case, and yield in that season was notably high for both mid and downstream respondents. In a short evaluation of this type further investigation is not possible. However low yield in the upstream areas of head and middle reaches may possibly be linked with the settling of pollutants.

Average wet season yield rose over the period from 3940kg/ha in 1991 to 4300kg/ha in 1993, a rise of approximately 10%. Dry season yield has undergone a similar improvement. Again it is difficult to identify the cause of these improvements, but it is not unreasonable to suggest that more certain water delivery will have a positive impact. Farmer's confidence in water delivery may encourage higher investment in inputs, which improves on yield in both seasons.

Gross margins

Gross margins per hectare have also risen over the period, but the change is not always proportional to change in yield, and is less consistent. Data needed to establish gross margins is complex and sometimes difficult to collect, and the results are potentially less reliable than for yield data. Results in Appendix 1 ratify yield data despite inconsistencies in some areas.

Performance in 1993 was more variable than in 1991. Headreach farmers appear to have made enormous increases to their margins while other farmers have improved less, and downstream farmers in the tail reach had a poorer year. There is no obvious explanation for this in the data. It is possible that changes in inputs which are not reflected by the cost data collected, could account for some of the new pattern. Further investigation would be required before these increases could be linked to water delivery. Because no satisfactory explanation of gross margin changes has emerged the 1991 gross margin figures were used in the calculations which follow.

4.2.3 Costs and benefits

The period under review has been one of change in several aspects of scheme management, including the operation of the sediment extractor. Thus factors other than the introduction of improved sediment management have influenced the performance of the irrigation system.

Actual irrigated areas, costs and benefits recorded over the study period have been used to update the earlier economic evaluation, with the aid of a number of assumptions:

a) The substantial increase in irrigated area seen between 1991 and 1992 cannot be entirely attributed to sediment removal by the sediment extractor. Desilting activities by the Philex Mining Corporation in 1992 had a large impact in this period. It was therefore assumed that the increase in irrigated area achieved in 1993 was a more realistic figure on which to base estimates of potential future increases in irrigated area. It has been assumed for simplicity that the relationship between volume of sediment removed and increase in irrigated area is linear. Limitations of this assumption are discussed later. Annual area increases of 4% are used in the calculation. In calculating the benefit from sediment extraction in 1991/2, 4% of the original area, i.e. less than a third of the actual increase was attributed to operation of the sediment extractor.

b) The analysis assumes that the concentration of sediment in the Agno River over the period for which data was collected is typical. In reality there will be quite large inter-annual variations around some long term mean. The volumes of sediment entering the scheme will increase with the increasing volume of water required to irrigate larger areas, and so increases in desilting costs will occur as the irrigated area expands. For this calculation we have assumed that desilting costs increase from the low point in 1993. The increase is proportional to the increase in the area irrigated, and so increases of 4% per annum are applied to costs.

c) It has been assumed that any benefit from IOSP desilting was lost when the scheme was inundated by mine tailing sediments. Calculation of costs in the previous study included two years of IOSP spending. This cost is now omitted. No cost is available for the desilting done by Philex Mines thus this cost is also omitted initially. As there is a risk that this omission will result in overestimation of returns, re-inclusion of initial desilting costs is undertaken in the sensitivity analysis.

d) Settling basins were included in the original sediment control facilities for ARIS but, as they are not yet built, construction costs which were included in the earlier evaluation have been omitted (Reference 1).

e) Actual cost of construction of the sediment control facilities remains unchanged at 4,200,00 pesos. Life of the facilities is still assumed to be a very conservative seven years.

f) Benefits were calculated by multiplying the additional hectares irrigated each year from 1991 by the average gross margin per hectare obtained by the sample farmers on the scheme. Results for 1991 and 1993 showed a dramatic but inconsistent increase from 11,066 pesos/ha in 1991 to 16,300 pesos/ha in 1993. There was no obvious explanation for this large rise in the corresponding yield data, thus in order not to overestimate benefits, it was decided to adopt the level of margin achieved in 1991 as constant for the years for which benefit was calculated.

g) If sediment control had not been introduced at Agno, sediment would have continued to accumulate in canals at a larger rate than it could be removed, and the service area would have continued to decline. The "without project" service area was assumed to continue to decline at the pre 1991 rate (Figure 4) in order to carry out this calculation (assumption g-1). In reality the rate at which the service area would have declined is difficult to predict, area reductions could have been less than assumed, perhaps as the result of more effective desilting etc. Thus an IRR was also calculated adopting the conservative assumption that there would be no further reduction in service area after 1991. This minimises the benefit attributable to the introduction of sediment control (assumption g-2).

The predicted series of benefits based on the assumptions g-1 and g-2 are tabulated below. Costs are based on NIA actual sediment removal costs up to year 4, after this they are based in assumption (b) above.

Estimated net benefits based on 1991-93 Performance

(Figures are million peso)

Year	**Annual benefit from production assumption (g-1)**	**Annual benefit from production assumption (g-2)**	**Cost of sediment removal**	**Net benefit assumption (g-1)**	**Net benefit assumption (g-2)**
1990	0	0	4.200	-4.200	-4.200
1991	10.690	2.612	1.900	8.790	0.712
1992	21.479	5.323	1.800	19.679	3.523
1993	32.379	8.145	1.300	31.079	6.845
1994	43.390	11.077	1.352	42.038	9.725
1995	54.522	14.131	1.406	53.116	12.725
1996	65.776	17.307	1.462	64.314	15.844
1997	77.163	20.616	1.520	76.642	19.095
Internal Rate of Return (IRR)				297%	89%

The rate of return achieved is larger than the 60% estimated prior to the operation of the sediment control facilities, Reference 1, due to lower figures for initial investment, (settling basins at the heads of lateral canals were not constructed), lower annual costs, and earlier assumptions concerning initial desilting and service areas.

4.2.4 Sensitivity analysis

Sensitivity analysis was carried out to investigate the effect of changes in the major assumptions that have been made. The results are summarised in the table below. In all cases, calculations are based on the conservative assumption of a constant “without project” service area.

Parameter	Assumption	IRR
Sediment quantities	Whole scheme desilted initially, first year desilting costs are 15.7 million pesos.	72% (Note 1)
	Sediment entering the system increased by 100% to 357,000 tonnes annually from 1993, annual desilting costs rise to 1,299,000 pesos	22% (Note 2)
Irrigated areas	No further increases in irrigated area occur and all other variables remain constant.	59% (Note 3)
Gross margins	An increase of 10% in gross margin between 1991 and 1993, with no further increase in later years.	93% (Note 4)

Note 1: Assumes benefit unchanged, (If the whole scheme had been desilted initially then in reality a much larger irrigated area than that assumed would be feasible).

Note 2: Budget restrictions would reduce the capacity of NIA to remove historical sediment deposits and increases in irrigated area would fall sharply to zero. Sediment monitoring data leads us to believe that such an assumption is excessively pessimistic. Nonetheless, the sediment extractor facility allows sufficient sediment to be extracted so that the cost of desilting does not exceed revenues from the Irrigation Service Fee (ISF). In a less extreme scenario sediment loads could increase for a year or two then reduce, so that "sediment mining" could begin again.

Note 3: With no further increases in irrigated area, expenditure up to 20,000,000 pesos on initial desilting would still result in a break even situation.

Note 4: The Rate of Return is not sensitive to small changes in gross margins.

Sensitivity analysis demonstrates that benefit occurs for even the most pessimistic assumptions. This is the case even though the benefit was calculated on the basis of the service area in 1991, ignoring the probable continuing decline in service area if improved sediment management had not been introduced.

Other benefits

The operation of the sediment extractor has enabled other policies already adopted by NIA to be successful. For example it is doubtful if field staff reduction, or the turnover of Type 1 contracts to IA's could have been achieved if the worsening sediment problem in ARIS had continued.

5. DISCUSSION

5.1 Financial implications for individual farmers

The financial implications of improved sediment control are largest for farmers who have previously had restricted access to irrigation water in the wet season. There will be two main categories in which an improvement in financial terms is expected. Firstly the farmers in "benefitted" areas of a system where supply was previously sub-optimal. Secondly, farmers who formerly relied totally on rainfall, but are now able to irrigate in the wet season. Increases in yield, and perhaps more importantly, reliable yields will lead to reliable income. At Agno, improvement in yield was approximately 10% between 1991 and 1993. The Gross Margin figures illustrated a substantial rise in farm income and although this increase was not used in the calculation of benefit on this occasion, the figures offer an optimistic indication.

It is generally recognised that farmers are more willing to invest money in inputs where irrigation water delivery is assured. An overall improvement in farm income is therefore expected when water delivery is improved. This will have two main outcomes for the irrigation system. Firstly a greater propensity for farmers to pay irrigation service fees and secondly reawakening of interest in management at IA level. Continued improvement in scheme viability can thus be expected as these effects reinforce the improvement in performance.

5.2 Financial implications for IAs

In the Philippines operation and maintenance of all but main canal systems is being handed over to IA's. Fee collection is also devolved to IA's who retain a proportion of service fee recoveries. As collection rates improve in response to more reliable water supply, IA's will have greater financial autonomy. However, they must also accept the reduced capacity of the irrigation agency to come to their rescue in times of need. IA funds must be set aside for routine maintenance and to cope with poor years or natural disasters.

5.3 Financial implications for the Irrigation Agency

By reducing the costs and the logistic demands of coping with sediment removal, NIA has been able to carry out at ARIS some policies which had previously seemed difficult or impossible to implement. NIA staff, although reduced in number, are more able to carry out their functions and have an improved relationship with the farmers within the service area.

Financial viability of the ARIS system, as defined by NIA, was achieved in 1993 for the first time in many years. The cost of desilting in 1993, including the sum spent on clearing some sediment deposited in the scheme prior to 1993, was approximately 2.5 million pesos, below the estimated total ISF collection (Table A1.9). As fee collection improves then the sum available for desilting should increase, which, in turn, should enable an increase in the rate at which historical sediment deposits can be removed, and the wet season irrigated area expanded. Larger irrigated areas will produce larger ISF collection, and an upward spiral could be established. However, limits set by the area that can be commanded, the proportion of river flow that can be diverted, and the capacity of the canal network will determine the final service area that can be achieved.

5.4 Technical issues

Most irrigation systems accommodate some sedimentation in canals without an immediate reduction in conveyance capacities. Although sediment settles on the canal beds, discharge capacities can be maintained by operating canals at a higher water level. This is usually the response of operators when canal discharge capacities reduce as a result of sedimentation. Eventually, rising water levels result in the canal freeboard limit being reached, and the conveyance capacity of some reaches is then limited by the danger of overtopping. As the sediment concentrations that can be transported drop at lower discharges, a larger proportion of the sediment entering a canal system deposits when the canals are silted. Thus a steep downward trend in the volumes of water delivered, and hence the area that can be supplied, often develops following an initial period with no apparent supply problems. This pattern can be seen in Figure 4 which shows the wet season irrigated areas for ARIS.

The link between sediment deposition, desilting practices, and the ability of a canal system to supply water, is complex. Hydraulic calculations can be made to estimate the benefit of, say, removing sediment deposits from the head reach of a main canal, but the task becomes daunting if calculations have to be made for an irrigation network. Even if this were feasible the results would provide no information on how long conveyance capacities would be maintained before canal reaches start to silt up.

For a preliminary evaluation the simple procedures described in Reference 1 can be used to make estimates of the sediment control requirement to maintain a target service area. However the results could have a wide margin of error, and this should be reflected in a sensitivity analysis when the economic assessment is carried out. Where it is appropriate numerical modelling using software that includes a sediment routing component is recommended. This enables the hydraulic performance of canal systems to be simulated for various sediment management scenarios, and provides predictions of both water deliveries and the quantities of sediment settling over complex irrigation networks. Modelling thus directly links sedimentation with the areas that can be reliably served. (A user friendly canal sediment routing model developed specifically for this application has been developed at HR Wallingford, and enables simulation modelling to be carried out by suitably qualified technical staff from an irrigation agency or local consultant.)

5.5 General discussion

In this report we have described an economic assessment at one scheme in the Philippines. While the analysis, described in Chapter 2 is general, the relative importance of the factors considered will change from system to system. At Agno the sediment problem was very severe, and large economic benefits were obtained by reversing a decline in the irrigated area. In cases where sedimentation rates are lower, the economic justification for improved sediment control would be based on savings in desilting costs.

Large reductions in desilting costs have been obtained from the introduction of simple, low cost, sediment control structures. For example the costs of constructing a vortex tube sediment extractor on the Chatra canal in Nepal, represented less than the cost saving achieved in the following three years through reduced desilting costs. The costs of constructing a simple vane sediment excluder in the Marbell II irrigation system in the Philippines represented less than one year of desilting costs for the sediments that where excluded. In both cases engineering interventions provided only a partial solution to existing sediment problems; complete solutions usually require larger investments. However, low cost, partial solutions are appropriate, when they reduce the amount of desilting to a level that can be sustained by the irrigation authority. Provided that reasonable estimates of the performance of the sediment control structure are available, the benefits in terms of reduced desilting costs are easy to quantify.

Recovery of irrigated area usually has a very large impact in a cost benefit analysis, and sediment control structures can be justified by a relatively small increase in cropped area. However, predicting the magnitude of area or yield increases is not trivial. In the retrospective study carried out at Agno, increases in irrigated area used in the economic analysis were based on observed data. This is clearly impossible in a study carried out to design and justify sediment control structures. A simulation approach provides the best means of deriving the technical information needed, but the farmers response to improved water supplies, and the willingness of those in former marginal areas to pay an irrigation service fee has to be carefully judged. Area and yield increases predicted as a consequence of improved sediment control should thus be viewed with some scepticism, and benefits should be treated conservatively.

A further benefit, which we have not attempted to quantify, is the impact on the farming community. Where schemes cannot remain financially viable using mechanical desilting, the farming community faces a return to rain fed farming, reducing incomes substantially due to lower yields, and destroying the opportunities for diversifying and a second crop in the dry season. In cases where systems are in terminal decline due to sedimentation problems this will need to be considered in a "without project" scenario.

6. CONCLUSIONS

6.1 Engineering conclusions specific to Agno RIS

The following conclusions are based on the 1993 observations:

6.1.1 The sediment control facilities removed 56% of the sand and coarser material entering the Agno main canal, and

6.1.2 The sediment control facilities reduced the volume of sediment settling in canals in 1993 from an estimated 39,700m^3 to 23,100m^3.

6.1.3 While these figures will vary from year to year as a result of varying river sediment loads, and the timing and quantity of water diversions, it is reasonable to expect that between 50% and 60 % of the coarser sediments (< 0.06 mm) entering ARIS will be extracted from the canal in future years, provided the structures continue to be operated effectively. Regular flushing of the escape channel during the wet season is vital if the performance of the sediment extractor is not to be impaired.

6.2 General engineering conclusions

6.2.1 Combining a sediment extractor, which continuously abstracts water and sediment from a main canal, with an intermittently flushed small settling basin, provided a flexible and economical means of sediment control that will have applications in other systems. The arrangement, shown in Figure 2, provides control over the coarser sediment fractions, while enabling a substantial proportion of flow abstracted from the main canal to be used for irrigation. It avoids the operational problems associated with a large flushed settling basin constructed in a main canal, or the high costs involved in constructing twin settling basins in the main canal which would be needed to maintain continuous irrigation supplies.

6.2.2 The study has highlighted the need to simulate the link between the quantities of sediment deposited in a canal system, and dredged from it, and the service area which can be reliably supplied. A numerical model which predicts sediment transport, deposition and reworking within irrigation canal networks is the most suitable means to establish this linkage. In cases where modelling is not appropriate approximate estimates of the desilting requirement to ensure a reliable water supply for a specified service area can be made using the method described in an earlier report (Reference 1).

6.3 Economic conclusions specific to Agno RIS

6.3.1 Monitoring carried out at Agno has confirmed the large economic benefits following the introduction of sediment control that were predicted in the earlier study.

6.3.2 The economic returns resulting from building the sediment extractor were positive even for the most pessimistic scenarios. If the costs of initial desilting the whole irrigation network, (which was not carried out) are counted, the benefits are restricted to the increase in irrigated area achieved by 1993, “without project area reductions are ignored, and gross margins are taken at the low 1991 level, an acceptable IRR was still obtained.

6.3.3 Financial viability has been improved for NIA, for IA's and for individual farmers by the construction of the sediment control facility. Financial viability for the system was achieved at ARIS in 1993 for the first time in many years. The cost of desilting in 1993, including the sum spent on clearing some sediment deposited in the scheme prior to 1993, fell just below the total ISF collection.

6.3.4 Expenditure on desilting in 1993 exceeded the estimated cost of removing the sediment which deposited, thus NIA was able to use its desilting activities to "mine" historic sediment deposits, providing the possibility of further increases in canal conveyance capacities and service area.

6.4 General economic conclusions

6.4.1 The utility of the economic evaluation procedure developed in the earlier study has been confirmed.

6.4.2 Sediment control facilities of the type adopted in this study are cheap relative to the annual costs of desilting schemes. They provide a quick economic solution because in many cases they pay for themselves in a few years.

6.4.3 Investment in sediment control is very small when compared with the value of an irrigation system which would otherwise face either a terminal decline in performance or require large sums to be spent in rehabilitation.

6.4.4 Economic returns resulting from the construction of sediment control facilities are likely to be influenced more strongly by increases in area served than by reductions in desilting costs. However, the operating agency receives only a proportion of the benefits of increased yields on the re-instated irrigated land, and so the financial viability of the operating agency will often be more strongly influenced by reduced desilting costs.

6.4.5 Construction of sediment control facilities without concurrent desilting works to achieve target canal conveyance capacities may prove uneconomic at some sites.

7. ACKNOWLEDGEMENTS

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Figures

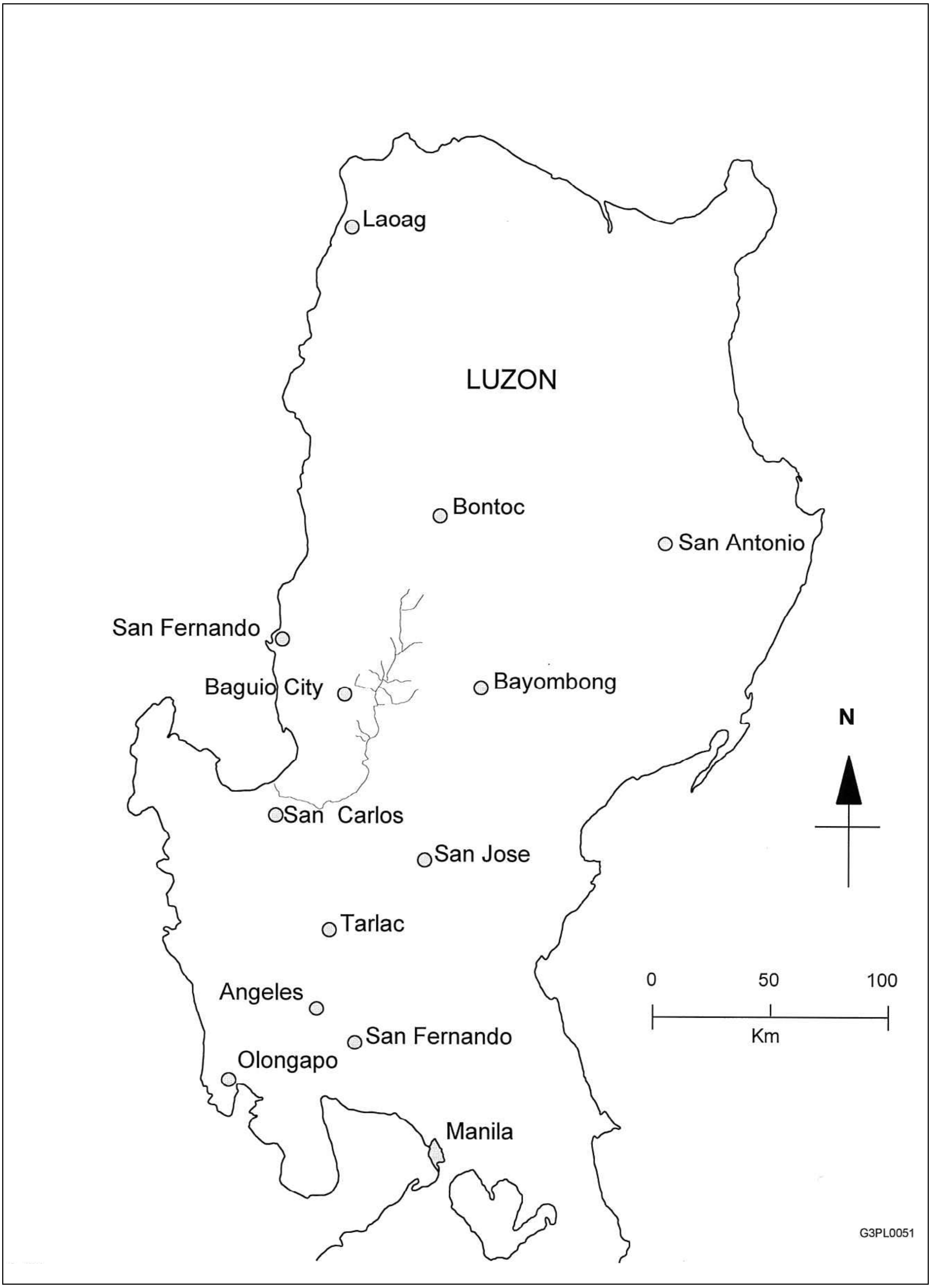

Figure 1 Location map

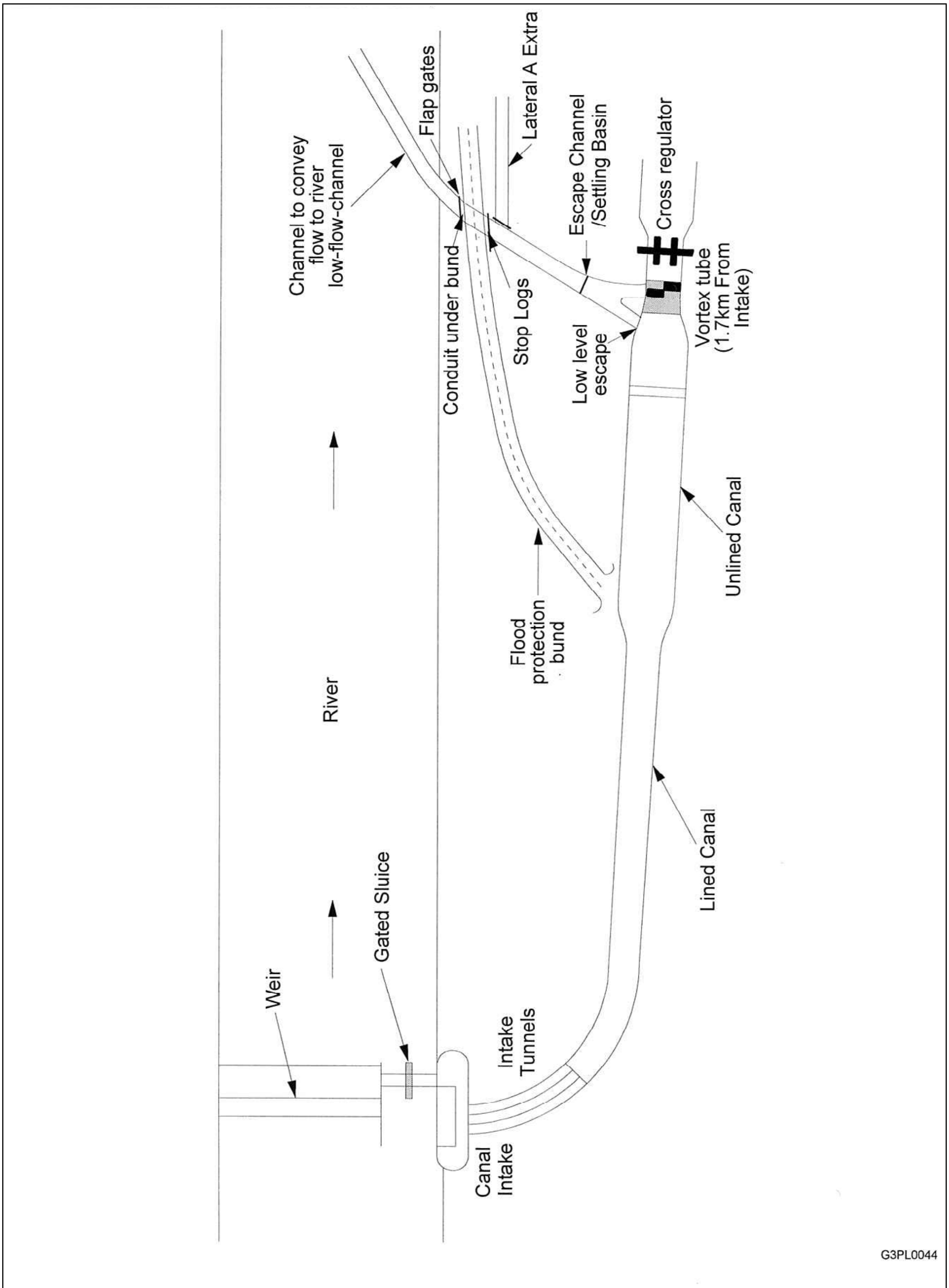

Figure 2 Agno RIS sediment extractor layout

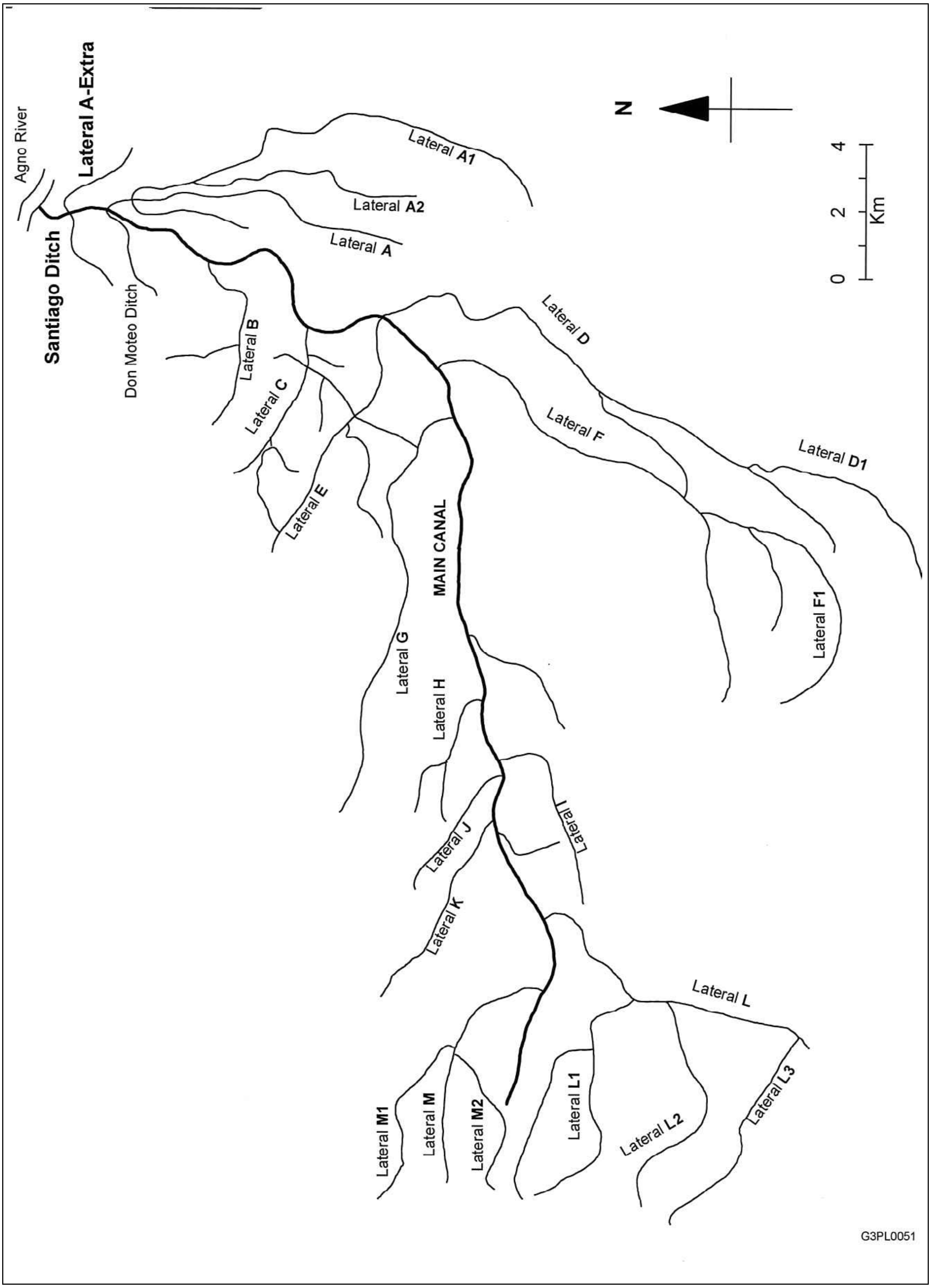

Figure 3 Agno RIS canal layout

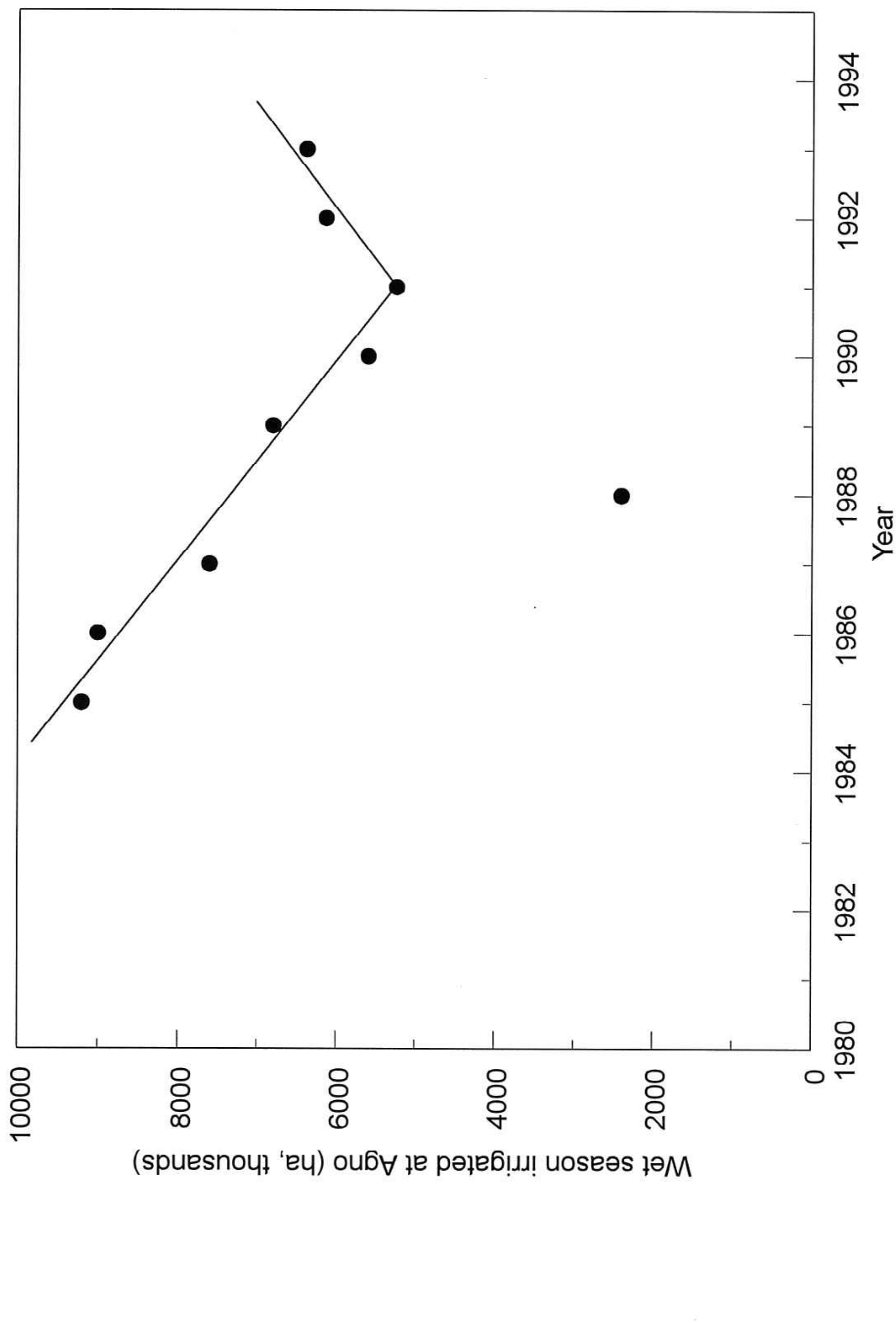

Figure 4 **Agno RIS wet season irrigated areas**

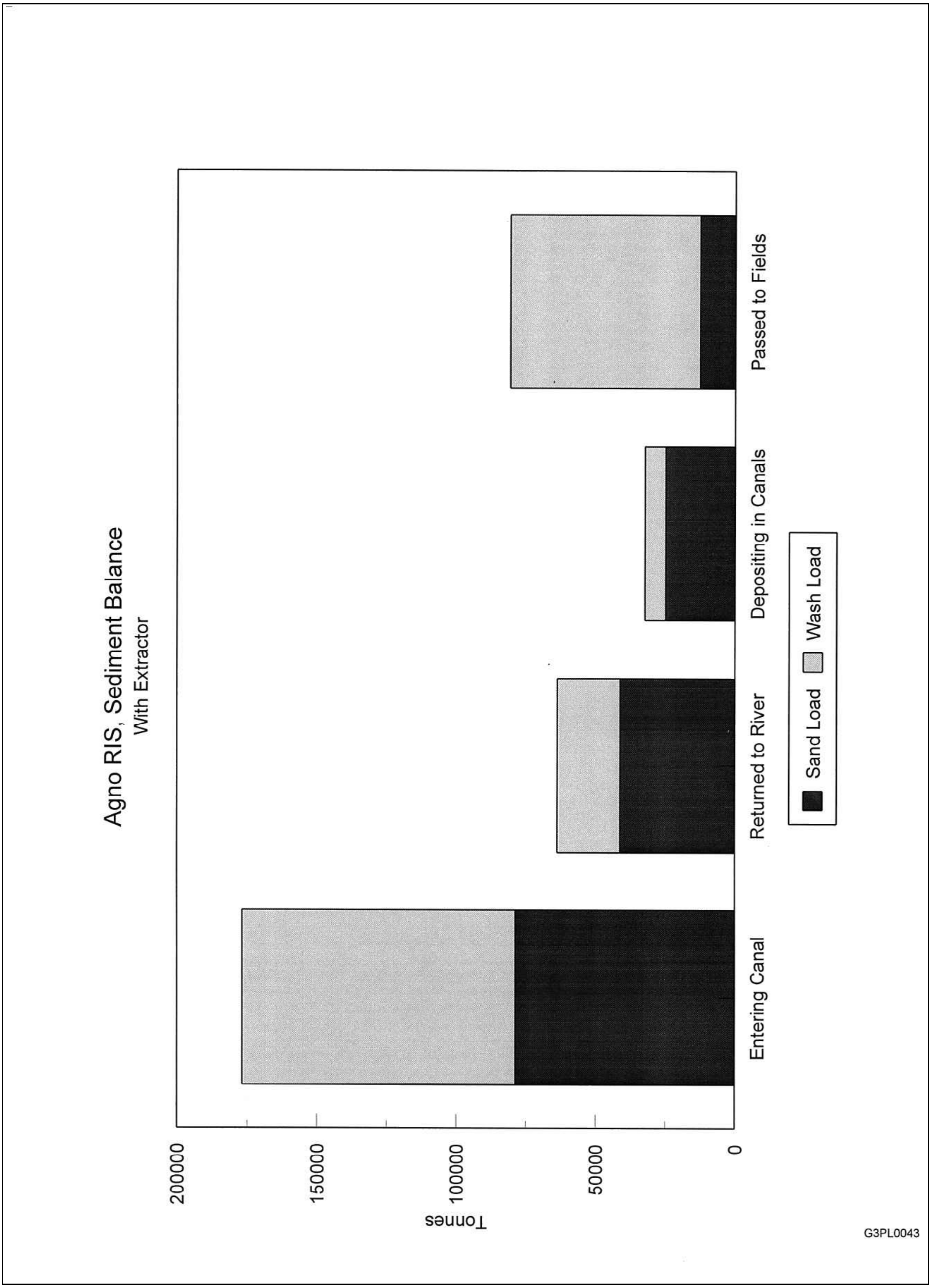

Figure 5 **Agno RIS 1993 sediment balance with sediment extractor**

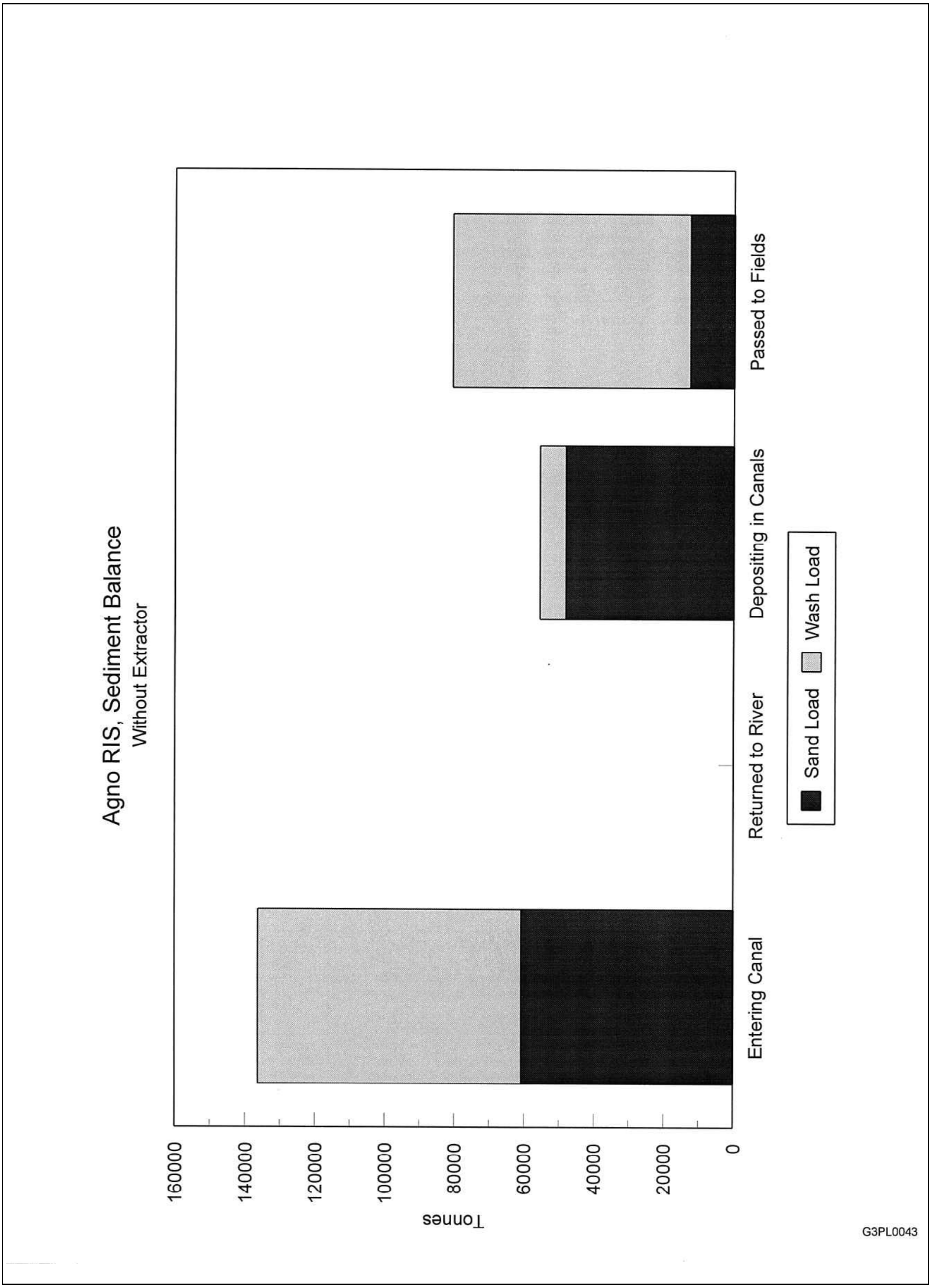

Figure 6 **Agno RIS 1993 sediment balance, estimated without sediment extractor**

Appendices

Appendix 1

Economic data

Appendix 1 Economic data

Table A Yield/ha in cavans of Palay for several Philippine irrigation systems

Irrigation System	Wet Season	Dry Season
Agno-Sinocalan	48	52
Lower Agno	48	-
San Fabian-Dumoloc	70	74
Ambayoan-Dipalo	56	55
Masalip	82	88
Amburoyan	89	90
Average, Dept of Agriculture Urdaneta, Pagasinan	85	50

These figures are scheme averages and probably reflect the fact that some farms had near-failure results. This may explain why average yield recorded for ARIS is well below that recorded for the sample of farmers in the same year. The Agno region was badly affected by drought in the dry season of 1991 explaining the low yield then. Agno-Sinocalan (ARIS) and Lower Agno achieved very low wet season yields. It is significant that both these systems draw water from the Agno River.

Table A1.1 NIA costs in pesos/annum for ARIS

	1991	1992	1993
Type 1 IA contract costs (1)	175,264	355,944	400,232
Machine costs	1,647,977	1,415,807	836,945
Total desilting costs	1,823,241	1,771,751	1,237,177
Field Staff costs	2,721,742	2,067,431	1,203,439
Office Staff costs	1,485,632	5,906,613	4,689,913
Total	6,030,632	5,906,613	4,689,913

Note 1: Costs incurred by NIA to pay Irrigator Assoications (IA's) to undertake desilting

Table A1.2 Irrigated areas 1991 - 1993 - ARIS

Area / Description	1991	1992	1993
WS Actual (ha)	5244	6135	6381
WS Benefitted (ha)	4439	5985	0
DS Actual (ha)	3865	959	3682
DS Benefitted (ha)	5865	740	3462
Total ISF (peso)	1401848	884,878	* 1222847

* Figures for incomplete year

Table A1.3 Wet Season Yield for 1991 in Kg/ha - ARIS

	Head Reach	Middle Reach	Tail Reach
UPstream	4100	3548	4113
MIDstream	3742	3983	4642
DOWNstream	3477	3672	4214
Average	3794	3705	4334

Table A1.4 Dry Season Yield for 1991 in Kg/ha - ARIS

	Head Reach	Middle Reach	Tail Reach
UPstream	4327	3843	3924
MIDstream	4091	4385	5183
DOWNstream	3374	3630	4208
Average	3933	3953	4438

Table A1.5 Wet Season Yield for 1993 in Kg/ha - ARIS

	Head Reach	Middle Reach	Tail reach
UPstream	2774	3434	3660
MIDstream	4479	6607	3699
DOWNstream	3491	6249	3669
Average	3581	5429	3676

Table A1.6 Dry Season Yield for 1993 in Kg/ha - ARIS

	Head Reach	Middle Reach	Tail Reach
UPstream	4734	-	-
MIDstream	5000	-	-
DOWNstream	3833	-	-
Average	4523	-	-

Table A1.7 Gross Margins Wet Season 1991 - Peso/ha

	Head Reach	Middle Reach	Tail Reach	Average
UPstream	13,182	11,252	13,574	12,660
MIDstream	9,859	10,996	10,876	10,475
DOWNstream	8,385	10,872	11,508	10,060
Average	10,339	11,089	12,012	11,066

No statistical differences in performance were found although observation suggests slightly better margins in upstream areas.

Table A1.8 Gross Margins Wet Season 1993 - Peso/ha

	Head Reach	Middle Reach	Tail Reach	Average
UPstream	18,905	12,289	22,574	17,923
MIDstream	21,990	9,975	11,196	14,327
DOWNstream	29,090	12,639	8,289	16,673
Average	23,329	11,574	14,020	16,300

No statistical difference in averages for UP-, MID- and DOWN stream. Headreach margins suggest a significant difference but are not easily understood as yield data does not support the data.

Table A1.9 ARIS Performance Evaluations

Year	Irrigation service fee collected	Other income of NIA ARIS	Total income	Collection efficiency
1991	1,410,848	1,379,666	2,709,514	16
1992	884,878	1,162,219	2,047,094	30
1993 [1]	1,222,874	599,241	1,782,088	50 [2]

Note 1: Results for the year only up to August 1993 approximately half a year

2: Expected efficiency for the year implying a final ISF between 2.5 and 3 million pesos

Appendix 2

Extractor design and sediment monitoring

Appendix 2 Extractor design and sediment monitoring

A2.1 Initial design

The assumptions and reasoning underlying the design of the sediment control facilities for the Agno River Irrigation System are described in Reference 11. Here a brief account of the design is given.

Sediment control facilities consist of a vortex tube sediment extractor and low level sluicing gates located in the main canal, both discharging into an escape channel which conveys the extracted flow and sediments back to the Agno River, see Figure 2. Vortex tubes operate by continuously extracting the bottom layer of the flow from the canal, which carries the majority of coarser sediments. For simplicity, the combined sediment extraction facilities are termed the "sediment extractor".

The location of the extractor was determined to ensure a sufficiently large head drop between the main canal and the Agno River to allow for the disposal of sediments. As there is evidence of a rising trend in the river bed levels at the outfall of the escape channel, which if continued will eventually prevent sediment disposal, a very short effective life for the extractors of 7 years was assumed. A cross regulator was constructed immediately downstream from the vortex tubes for control of the water level in the canal head reach upstream from the extractor.

The extractor was to be operated in two modes, depending on the availability of excess water for sediment flushing. During the dry season, when there is a relatively low discharge in the canal, and excess water is not available to operate the vortex tubes, the cross regulator was to be operated so as to pond the flows in the headreach. Sediment that settled in the headreach would then be sluiced back to the river through the low level sluicing gates incorporated at the extractor site. As the sediment concentrations transported in the river during dry season flows is quite low it was estimated that flushing would not need to be carried out more frequently than once a month.

The low level sluice gates can be kept open for an extended period prior to the wet season, when the canal is closed for maintenance. This practice should help to clear the canal headreach of sediments, and provide some storage for future sediment deposition.

In the wet season, when larger discharges can be diverted from the river than are needed for irrigation, the vortex tube sediment extractor was to be operated continuously, with the flow and sediment diverted from the canal being passed back to the river via the escape channel.

The facilities described above were designed to extract sands and coarser material from the canal. Finer material causes conveyance problems in the smaller canals of the system, which have a lower capacity to transport sediments. Construction of small settling basins at the heads of the lateral canals was also recommended, (Reference 11), to trap finer sediments. The basins where to be desilted when required using machines, but were not constructed during the period covered by the study.

A2.2 Revised operation for 1993

The failure of Philex Mining Corporation's tailings dams in January 1992 caused extensive sedimentation both in the Agno River and in the irrigation system. Sediment concentrations approaching 10,000 ppm were measured entering the canal, the canal headreach was filled with mine tailings, and irrigation ceased. Extensive desilting was subsequently undertaken with funds provided by Philex Mining Corporation, and irrigation recommenced in the wet season of 1992. The sediment extractor had no effect on the very high sediment loads diverted to the canal in the early part of the 1992 irrigation season, which blocked the main canal upstream from the vortex tube. Its later operation, following desilting of the main canal, was compromised by interventions from farmers diverting water from the escape channel, and misoperation of the main canal cross regulator.

The alignment of an existing small Lateral (lateral A Extra) was used to construct the vortex tube escape channel, so as to minimise delays and minimise the expense involved in additional land procurement. While this enabled construction to proceed quickly, it caused problems later. An offtake from the escape channel was constructed immediately upstream from the entrance to the conduit under the flood bund, Figure 2, to maintain supplies to the small area originally supplied from Lateral A Extra. However, the availability of reliable large discharges in the escape channel, led to an expansion of the area supplied by lateral A extra, irrigated with water carrying high sediment concentrations. This soon caused severe sedimentation problems in the lateral. As a higher water level in the escape channel was required to supply the lateral farmers used brushwood to head up the escape channel flows at the entrance to the conduit through the flood bund. This reduced the flow which could be extracted from the main canal through the vortex tube, and caused sediment to deposit in the escape channel.

A further problem arose when the gates on the canal cross regulator were adjusted by farmers so that most of the main canal discharge passed over the left hand vortex tube for long periods. With no flow over the tube the vortex action was eliminated and sediment settled in the tube, which subsequently blocked.

These factors resulted in a serious reduction in the effectiveness of the sediment extractor in 1992, and continued despite the construction of a small new canal, parallel to the escape channel, to supply water to Lateral A Extra directly from the main canal. Both problems were largely solved at the start of the 1993 wet season, when new operational procedures were adopted for the sediment control structures.

In order to prevent high sand concentrations from passing into Lateral A Extra the design water level in the escape channel was raised, using flash boards placed at the entrance to the conduit passing under the flood bund. The increased levels ponded the flow in the escape channel, forming a settling basin, which trapped most of the coarser sediments ejected from the canal by the vortex tube. This had already happened in the earlier period due to farmers interventions, but the provision of flash boards allowed the sediment accumulated in the escape channel to be flushed back to the Agno River. Flushing discharges were supplemented when necessary by partially opening the low level sluicing gates, and flushing was carried out weekly to ensure that the operation of the vortex tube was not compromised by sediment deposition.

This arrangement was possible as a large bed width and freeboard had been specified in the original design of the escape channel, to provide for sediment flushing from the main canal at high discharges. However it provided an improvement to the original design concept as most of the water diverted through the vortex tube could now be used to irrigate an increased land area supplied by Lateral A Extra, reducing the quantity of water "lost" in sediment flushing. (Intermittent flushing of the escape channel requires far less water than was needed when the extracted discharges were diverted directly to the river.)

A2.3 Sediment measurements, 1993

Sediment monitoring was carried out to quantify the effect of the sediment extractor on the sediment loads passed to the irrigation system. Figure A2.1 shows the location of the sediment monitoring points, and Table A2.1 summarises the measurements that were made. Sediment measurements were carried out to a high standard by Research Staff from NIA's Urdeneta office, using equipment supplied for an earlier ODA funded study, and the measurement techniques recommended by HR Wallingford.

Sand and washload concentrations entering the canal were measured at the outlets of the tunnels at the head of the main canal, and at the other locations shown in Figure A2.1. The pump sampling technique was applied: a nozzle was placed in the flow using a sampling mast and a large water sample was pumped from the canal and passed through a 0.063 mm sieve to separate the sand sizes in transport from finer washload sediments. The weight of sand collected on the sieve and the water volume, measured using a bucket, were used to determine the sand concentration. A current meter was attached to the sediment sampling mast and discharge measurement was made at the same time as the sediment concentration measurements. Measured water velocities and sediment concentrations were used to calculate sediment loads, (tonnes per second), from the sediment concentration data.

Measurement at four heights on the centreline of each of the six outlet barrels, or at two or more verticals at the other measurement locations, enabled the mean sediment concentration to be established. This was computed by fitting a theoretical sediment flux distribution to the measured values, and integrating this profile to yield the mean sand concentration.

Wash load concentrations were also measured, using bottle samples, but they were not used in the assessment of the performance of the sediment extractor, which was designed to extract sediments in the sand size range from the canal. Wash load sediments contribute to the material settling in the canal system, and thus are included in the sediment balance computed for the canal system. Measurements where carried out following the schedule shown Table A2.1

More details of the pump sediment sampling method, and the procedure used to analyse pump sampling data are given in Reference 12. The likely errors of the sand concentration measurements were assessed using the method outlined in Reference 12, and indicate that the overall standard error in the sediment loads, when averaged over the season, are expected to be about 13%.

Estimates of the sediment volumes settling in the escape channel, and being flushed back to the Agno River, were made by surveying the bed level in the escape channel before and after flushing. The measured sediment quantity entering the escape channel was derived thus from sediment load measurements, and also flushed from the channel (derived from bed level surveys) indirectly from the sum of sediment mass and observed sediment loads passed to Lateral A Extra. These sediment quantities agreed to within about 20 %. This is well within the expected error for this type of comparison, where a sediment mass derived from occasional sediment sampling is compared with a volume derived from surveys, assuming a standard value for the density of the sediment deposits. This result provides confidence in the sediment load measurement data.

A2.4 Results

Table A2.2 presents the results of the discharge, sand load and wash load monitoring at the canal head, the cross regulator and the head of the escape channel. Table A2.3 presents the results of monitoring at the head of Lateral A Extra, which was undertaken on different days from the other sediment monitoring. Table A2.4 presents the results of the bed elevation surveys in the escape channel before and after each flushing.

These results were converted into a wet season sediment balance, using the assumptions listed below.

a) Some sand sized material was found to be depositing in the main canal headreach upstream from the sediment extractor. It was assumed that this material would be flushed from the canal headreach and back to the Agno River during the annual flushing prior to the wet season.

b) It was assumed that 10% of the wash load passing the sediment extractor was depositing in the canals of the irrigation system. This figure was derived in Reference 1.

c) The sand concentrations passing to the fields was estimated as 74 ppm. The HR Wallingford software for computing sediment concentrations in settling basins (DOSSBAS, 1995) was applied to a relatively small canal typical of those in the system. ($0.5m^3/s$ discharge, 2m bed width and 0.0002 slope (1/5000)). Results shows that 74ppm of fine sand could be transported by the canal and that about 90% of the deposits in the canal would be of sand sizes when reasonable estimates for wash load settling velocities were taken. This value agrees with the estimate given by JICA (Reference 8).

d) The dry density of deposited material required to convert the quantities given as tons to deposited sediment volumes has been assumed to be $1.4t/m^3$.

Table A2.5 presents the wet season sediment balance.

The values given in the table can be used to determine the trapping efficiency of the sediment extractor. Of the 52,500 t of sand entering the canal, 27,500 t was diverted to the river, a trapping efficiency 52%. This figure includes 1,900 tonnes of sand which was extracted from the canal, but was then diverted into Lateral A Extra. A trapping efficiency is usually determined for all sand that is extracted from a main canal, and with this definition the trapping efficiency rises to 56%.

In order to derive annual totals for the quantity of sediment settling in the canal, the wet season totals were increased to account for a short period at the start of the season when data was not collected, and the dry season period following the measurements. Dry season totals were estimated on the basis of the dry season irrigated area and the assumptions described in Reference 1. The computed sediment balance for the whole of the 1993/94 irrigation period is shown in Figure 5.

Table A2.1 Sediment Measurement Programme

LOCATION	MEASUREMENT FREQUENCY (per week)						
	Sand X	Washload X	Water Level	Discharge	Gate Opening	Bed EL and Bed Samples	Temp
1 River Intake	-	-	7	-	7	-	-
2 Head Main Canal	2	2	7	-	-	-	2
3 MC Upstream from Extractor	-	-	2	2	-	2	-
4 Vortex tube and Low Level Escape	-	-	7	-	7	-	-
5 Cross regulator	2	2	7	2	7	-	-
6 US end Escape Channel	2	2	7	2	-	-	-
7 Along Escape Channel	-	-	7	-	-	2	-
8 Entrance to Lateral A Extra	2	2	2	2	2	-	-

Table A2.2 Sediment monitoring at canal head and at sediment extractor, 1993

Date	Entering canal			Cross regulator			Entering escape channel		
	Discharge m^3/s	Sandppm	Washloadppm	Dischargem^3/s	Sandppm	Washloadppm	Dischargem^3/s	Sand ppm	Washloadppm
13/8/93	20.2	329	545	13.8	255	564	6.4	506	255
16/8/93	21.0	523	471	13.6	187	-	7.4	326	518
23/8/93	27.1	433	673	21.5	419	745	5.6	653	945
27/8/93	20.3	172	273	15.2	118	345	5.1	376	36
30/8/93	23.6	1047	545	18.7	453	600	4.9	736	607
3/9/93	18.7	214	411	14.3	104	445	4.4	217	625
6/9/93	18.0	208	500	14.2	156	482	3.9	456	500
10/9/93	24.4	990	870	20.2	826	561	4.2	1467	870
13/9/93	No sediment samples collected due to pump malfunction								
17/9/93	18.5	567	709	14.8	399	709	3.7	702	768
20/9/93	19.9	625	518	16.8	212	655	3.1	507	636
24/9/93	4.5	56	304	1.7	45	436	2.7	107	429
27/9/93	12.9	481	286	9.2	330	345	3.7	725	382
1/10/93	20.6	959	527	15.0	88	455	5.6	269	382
4/10/93	Canal closed during measurements								
11/10/93	Canal closed from 5th to 10th inclusive due to typhoon Kadiang								
15/10/93	9.7	186	471	7.8	146	416	1.9	699	434

Table A2.2 Sediment monitoring at canal head and at sediment extractor ,1993 - continued

Date	Entering canal			Cross regulator			Entering escape channel		
	Discharge m^3/s	Sandppm	Washloadppm	Dischargem^3/s	Sandppm	Washloadppm	Dischargem^3/s	Sand ppm	Washloadppm
18/10/93	10.3	78	536	8.6	50	571	1.7	264	607
22/10/93	10.0	65	273	6.4	7	235	3.6	48	-
25/10/93	8.3	24	179	5.0	5	250	3.4	27	214
29/10/93	15.7	53	161	17.8	56	143	3.0	218	179
5/11/93	8.1	169	179	4.0	38	212	4.2	69	268
8/11/93	13.9	50	327	11.6	9	339	5.6	34	214
12/11/93	13.3	74	396	8.4	20	286	4.7	245	357
15/11/93	12.0	23	161	13.3	2	125	5.9	41	127
19/11/93	14.5	7	1121	11.8	27	1268	4.5	80	1429
22/11/93	12.4	8	143	8.8	4	90	5.0	23	-
26/11/93	16.5	-	107	12.1	9	161	4.9	46	345
29/11/93	13.8	-	1143	9.1	7	536	5.3	31	500

Table A2.3 Sediment loads and discharges entering Lateral A Extra, 1993

Date	Discharge m^3/s	Sand concentration ppm	Washload concentration ppm
24/8/93			273
25/8/93	Flushing		
26/8/93	0.28	445	
31/8/93	0.27	254	909
1/9/93	Flushing		
7/9/93	1.01	724	673
8/9/93	Flushing		
14/9/93	0.57	4304	527
15/9/93	Flushing		
16/9/93	Flushing		
17/9/93	0.21	95	732
21/9/93	0.29	629	446
22/9/93	Flushing		
23/9/93	0.43	223	429
28/9/93	1.10	45	250
29/9/93	Flushing		
30/9/93	0.48	114	382
12/10/93	1.98	211	505
13/10/93	Flushing		
19/10/93	1.05	3	199
20/10/93	Flushing		
21/10/93	0.20	23	180
26/10/93	0.63	69	290
27/10/93	Flushing		
28/10/93	1.29	23	127
3/11/93	Flushing		
4/11/93	0.95	54	554
9/11/93	0.78	119	249
10/11/93	Flushing		
11/11/93	0.72	204	204
16/11/93	0.70	67	145
17/11/93	Flushing		
18/11/93	0.33	10	36
23/11/93	1.09	129	214
24/11/93	Flushing		
25/11/93	0.57	70	252

Table A2.4 Results of bed elevation surveys in escape channel, 1993

Date	Volume in escape channel (m^3)	Volume flushed (m^3)
24/8/93	1134	
25/8/93	Flushing	479
26/8/93	655	
31/8/93	1372	
1/9/93	Flushing	726
2/9/93	646	
7/9/93	696	
8/9/93	Flushing	168
9/9/93	528	
14/9/93	878	
15/9/93	Flushing	292
16/9/93	Flushing	
17/9/93	586	
21/9/93	987	
22/9/93	Flushing	127
23/9/93	860	
28/9/93	979	
29/9/93	Flushing	250
30/9/93	729	
12/10/93	916	
13/10/93	Flushing	290
14/10/93	626	
19/10/93	903	
20/10/93	Flushing	318
21/10/93	585	
26/10/93	591	
27/10/93	Flushing	176
28/10/93	415	
3/11/93	Flushing	91
4/11/93	324	
9/11/93	617	
10/11/93	Flushing	77
11/11/93	540	
16/11/93	662	
17/11/93	Flushing	113
18/11/93	549	
23/11/93	608	
24/11/93	Flushing	36
25/11/93	572	

Table A2.5 Sediment Balance, 1993 Wet Season

	Entering canal (t)	Returning to the river (t)	Depositing in canals (t)	Passing to fields (t)
With the Extractor: Sand	52,500	27,500	16,600	8,400
Wash load	65,400	15,000	5,000	45,400
Total	117,900	42,500	21,600	53,800
Without the tractor: Sand	40,500	0	32,100	8,400
Wash load	50,400	0	5,000	45,400
Total	90,900	0	37,100	53,800

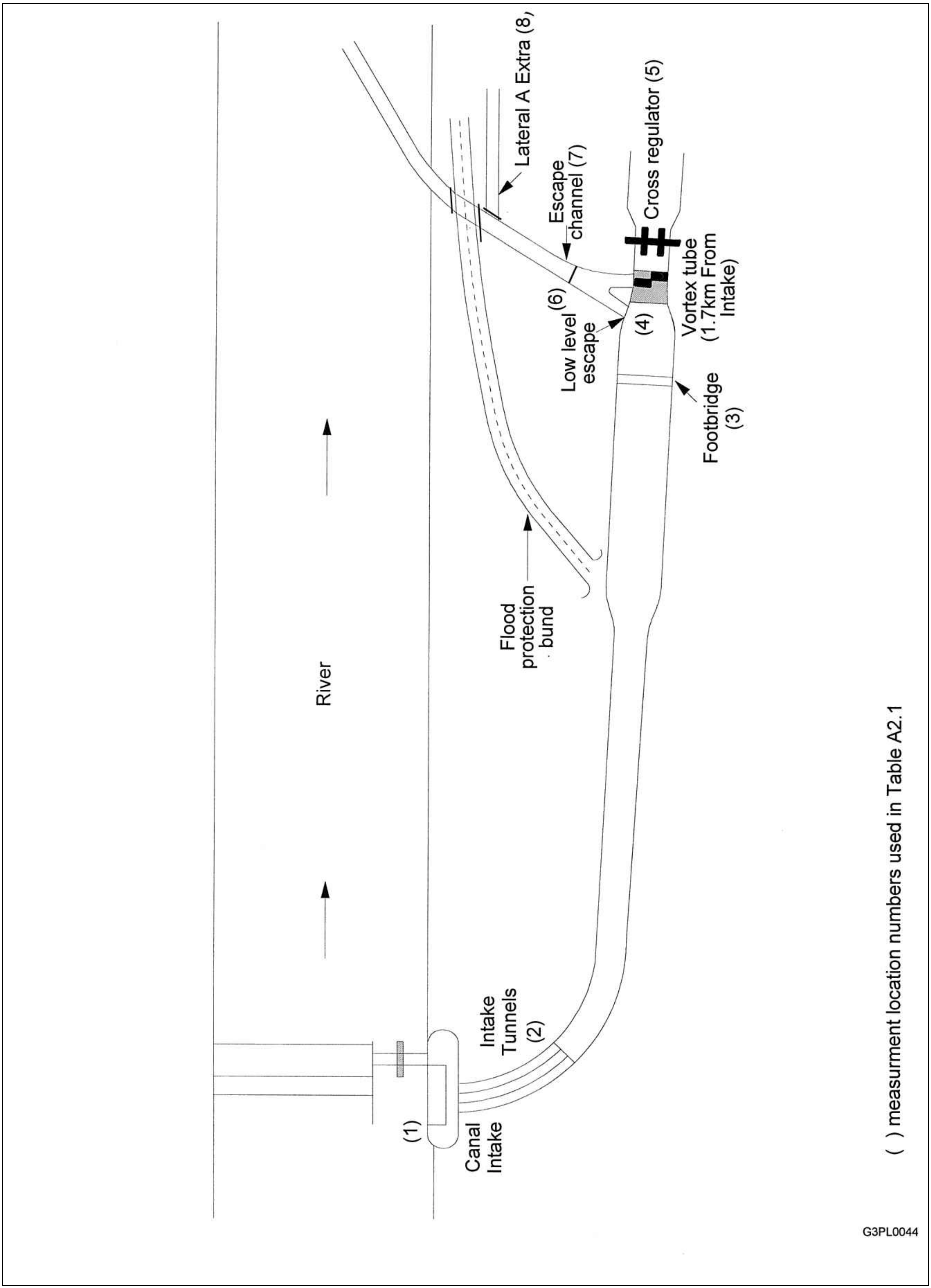

Figure A2.1 Sediment monitoring measurement locations