A SOUTH AFRICAN CASE STUDY ON SEDIMENT CONTROL MEASURES WITH THE USE OF SILT TRAPS IN THE COAL MINING INDUSTRY

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ABSTRACT

The development of a comprehensive sediment control plan is a vital element of an effective mine site water management system. If left unattended, the deposition of silt in areas where adequate provision has not been made could result in a considerable cost to both the mine and the environment. In the coal mining industry, the management of the suspended residue can be either through the use of a silt trap or by creating a dam with sufficient capacity to be able to accommodate the silting up of the facility over time.

Sediment traps and basins provide a cost effective means to reduce the amount of suspended solids in surface runoff. Design criteria along with the level and regularity of maintenance required for sediment control measures are the key issues to their success. Through a desktop study of typical silt traps found in the coal mining industry, one can draw conclusions as to the inputs required for the design and the advantages and disadvantages specific to each type.

The alternative of constructing a dam with enough capacity to allow for the deposition of the silt over time has the advantage of not being required to be continuously maintained, however extra cost is associated with this option. Careful consideration and a comprehensive management plan is needed for the effective management of suspended coal residue in the dirty water.

The paper will conclude by analysing why so many of these sediment control measures are perceived to have failed, and what measures should be in place in order to ensure that a settling facility remains effective and operational over its design life.

1. INTRODUCTION

Surface Water Management in Coal Mining

It is in the best interest of both the mines and the environment to minimise the quantity of dirty water generated through operations. Through careful management of keeping as much as possible of the clean runoff separated from the dirty areas, a mine can reduce both costs and its longer term environmental liability. Figure 1 shows an example of a typical clean water diversion around the workings for a coal mine. The red outline showing the catchment area that will generate dirty water, with the blue line illustrating the diversion of clean water. The mining area illustrated in Figure 1 will also be used as one of the case studies presented in this paper.

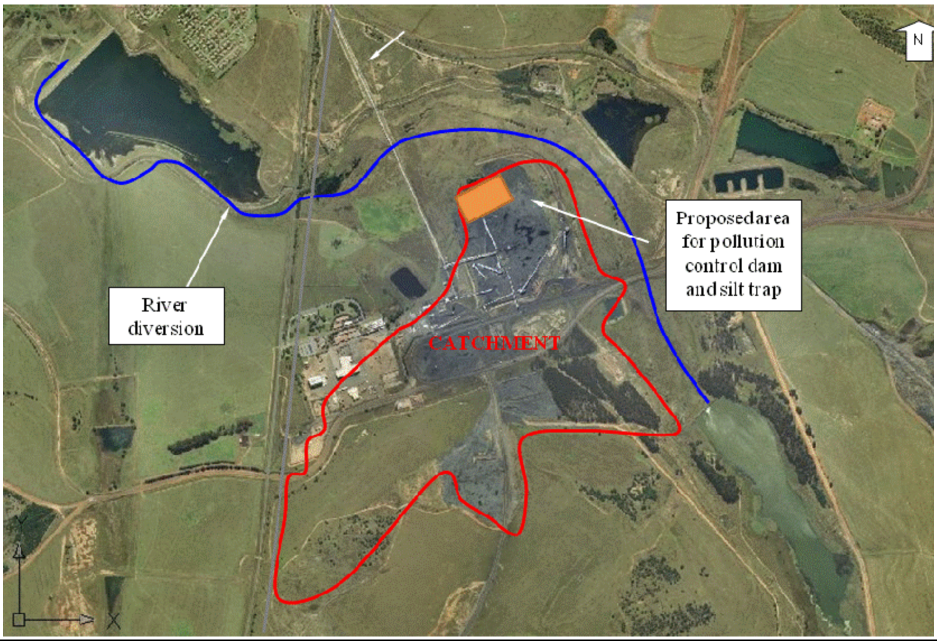

Figure 1. Clean and dirty water management in a typical coal mine (Aschenborn, 2005)

Sediment Control Measures

Sediment control is an important part of an effective dirty water containment system. Dirty runoff from mine workings and stockpile areas contains coal residue that can cause silting up of canals and pollution control dams. Figure 2 shows a dirty water canal that has over time been completely silted up. Due to the excessive silting, the dirty water management for this specific area has become ineffective as the canals and dam have no more capacity left to accommodate the runoff. The result of this is that the dirty water is allowed to flow into clean catchment areas which causes negative impacts to the environment.

Figure 2. Silting up of dirty water canal

It is necessary to have adequate measures in place to deal with the collection of mine residue in the dirty water make. Two options can be considered in the design of a sediment control facility, firstly to have a small pond or trap which contains the sediment before being discharged in the dirty water dam. The other possibility is that a collection facility be built with adequate storage in order to contain the flow and effective silting up over its design life. While these measures seem simple, it is interesting to note that many sediment control measures are perceived to be failing in the coal mining industry.

This paper will investigate different options for removing the suspended coal residue through the use of case studies and comment on what is required in order to ensure an effective and operational system.

2. SILT TRAPS

According to Warner (1992) sediment traps or basins are used to primarily accomplish two functions, namely the reduction in peak flow and the trapping of sediment. He proposed that the efficiency of basins to accomplish these two functions is directly related to the basin design with respect to:

- Location and gradient of inflow channels;
- Selection of type, size and location of principal and emergency spillways;
- Length to width ratio of the pool;
- Basin shape;
- Percentage of basin capacity allocated to sediment and permanent pool storage;
- Dewatering methods;
- Detention storage;
- Inlet baffles;
- Use of flocculation additives.

Trap Efficiency

Heinemann (1981) suggested that the single most informative characteristic of a reservoir or dam is its trap efficiency. Trap efficiency, defined as the percentage of sediment that remains in the facility of that which enters it, should ideally be low in the water retaining structure (dam/reservoir) and high in the sediment trap or basin (Verstraeten and Poesen, 2000). Trap efficiency in basic terms is given as follows:

$$\text{Trap efficiency} = \frac{S_{settled}}{S_{inflow}}$$

Where;

$S_{settled}$ is the sediment mass remaining in the trap

S_{inflow} is the sediment mass entering the trap

Although the definition may seem over simplified, the control measures put in place in order to achieve a high trap efficiency in silt traps requires a well thought through design and an adequate knowledge of the particles suspended in the dirty water generated from the mine.

Particle Distribution and Settling Time

The grading of the suspended coal residue entering the sediment trap is important in determining what percentage of the material will be settled in the trap. Courser material will have a faster settling velocity, whereas the fines will take a longer time to settle. Figure 3 shows the grading of 3 samples which are representative of typical carbonaceous material to be settled in a sediment trap.

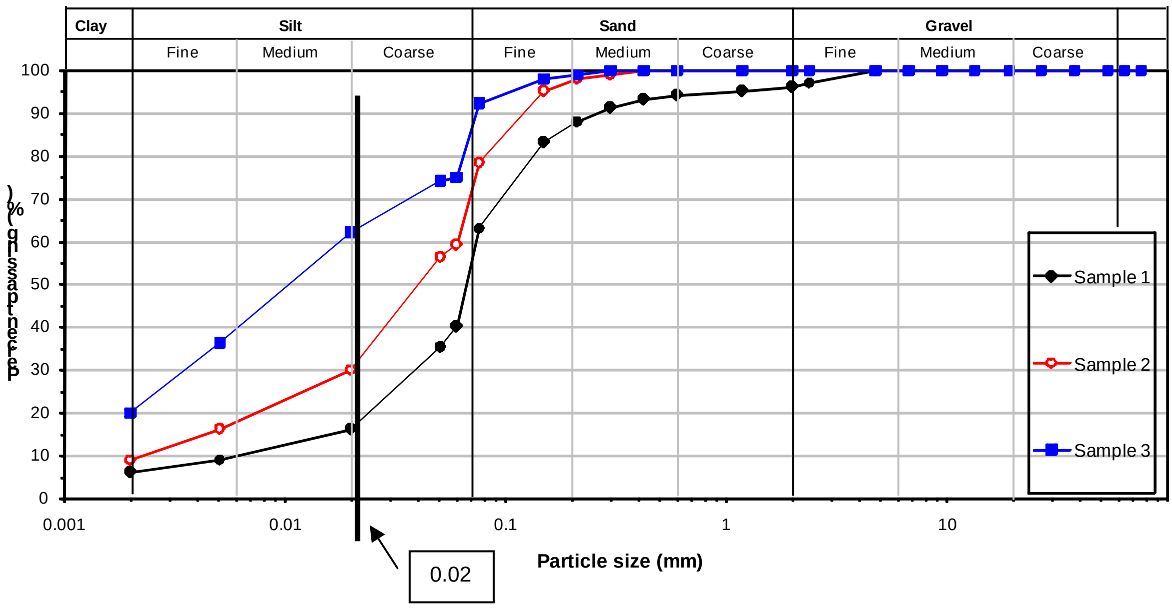

Figure 3. Grading of 3 silt samples

The samples were taken from areas on a coal mine where coal residue had been deposited. As can be seen from Figure 3 the materials have a high percentage of fines with sample 3 consisting of more than 60% particles less than 0.02mm in diameter. Using Stokes law theory, a vertical settling velocity can be calculated for the suspended particles entering into a silt trap assuming that the particles are spherical. In order for a silt trap to serve its purpose and to maintain a high efficiency, the particles should fall below the outlet level before reaching the opposite of side of the trap.

The smaller the particle size, the less it will weigh and therefore have a smaller downward force exerted. Particles with smaller diameters will therefore take longer to settle and it was noted that particles less than 0.02mm became impractical to model theoretically. A reasonable line needs to be drawn as to the minimum particle size to be considered in estimating the trap efficiency of silt traps.

Inputs to Design

The design of a dirty water dam is generally considered standard with the capacity required such that the dam does not spill for at least the 50 year storm event. For the design of silt traps there are, however, a number of different views as to the optimum design characteristics. One of these standards, developed by the Province of British Columbia (1996) for the design of sediment control measures in the mining industry advises that:

- Design flow for removal of suspended solids in sedimentation ponds should correspond to the 10-year, 24-hour flood flow.
- Easy removal of sediment at regular intervals
- Preferred shape of sedimentation ponds is generally rectangular with ratio of length to width of about 5 to 1.
- Unless there are mitigating factors, the pond should be sized to provide not less than a 20 hour detention time for a 1 in 10 year flood flow.

The above standards are recommendations given as to effective silt trap design. There are however many different views as to what practically works in the industry.

3. CASE STUDY 1

The first case study area (shown in Figure 1) is for a mine where the operations and an ineffective sediment control plan have resulted in the silting up of the dirty water canals and pollution control dams. This is a typical problem associated with dirty runoff in the coal mining industry. If the collection of silt in the dirty water dams is left unattended, the result is an expensive operation on the part of the mine to rectify the situation.

Design

The capacity of the pollution control dams, as well as the size of the sediment trap, is dependant on the runoff that can be expected from the dirty area being drained into these facilities. Typically the runoff expected to enter a trap will be in part from rainfall and also from operations such as the washing of vehicles and plant taking place at the mine. Due to limitations on space, this silt trap has been built for the containment of dirty water from normal runoff and has not accommodated for larger storm events.

The silt trap comprises of two parallel bays. The entrances to these bays are equipped with 150mm high slats to allow run-off to be channeled into either one of the bays. The system was designed such that both bays would be used during normal operations. Having a dual bay system does have advantages; during times of low flows the entrance to one of the bays could be closed off, giving the settled silt time to partially dry out which will make removal of this material easier. Three slats (450mm high) have been designed for at the end of each bay which makes the option available of draining the facility, either entirely or at different levels. Figure 4 shows the layout of the silt traps and pollution control facility.

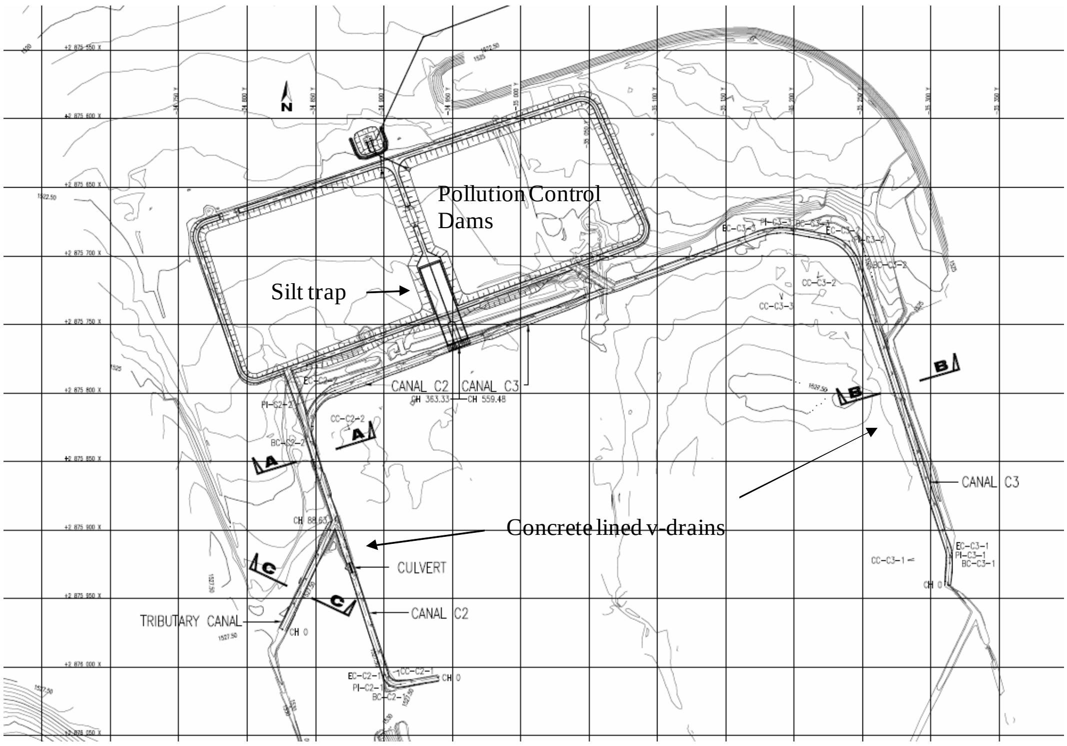

Figure 4. Location of silt trap and pollution control facility – Case study 1

Trap Efficiency

Based on the assumption that particle sizes less than 0.02mm will not settle within the required time (from when the particle enters the trap to before it reaches the opposite end), the estimated trap efficiency was calculated to be 65%. Figure 5 shows the design of the silt trap with a width of 15m and a length of 45m.

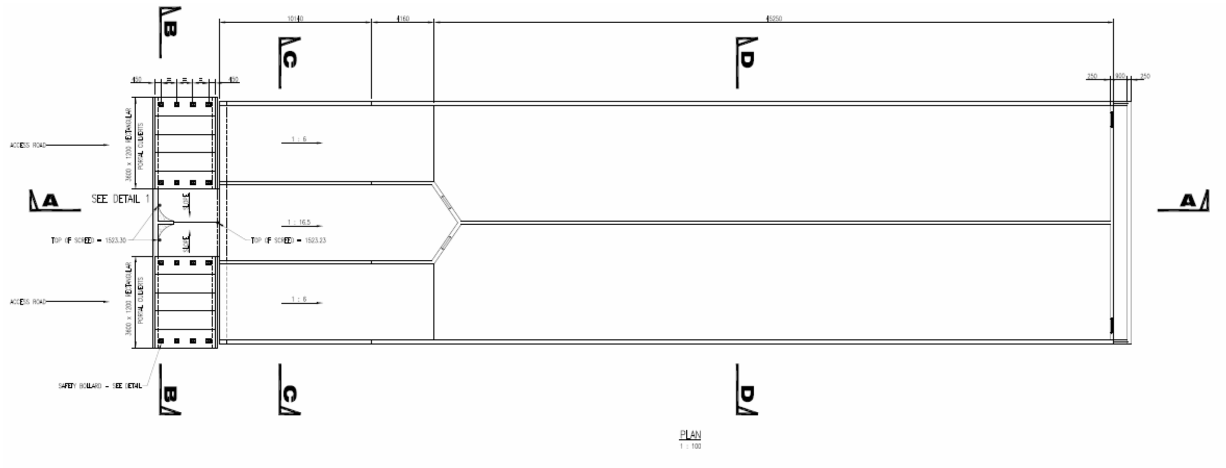

Figure 5. Design of silt trap; plan and horizontal view

Maintenance

The silt trap is recommended to be cleaned out regularly, but preferably before the silt level reaches 450mm, i.e. the depth of the top slat. As mentioned previously, the advantage of this design is that when cleaning is to be carried out, one of the bays can be closed off. Cleaning out can be done using a TLB, which can become difficult to operate if the level of silt is too deep.

When full, each bay should contain about 155m^3 of carbonaceous slurry, which is sufficient capacity for normal runoff but will not be able to accommodate a large storm event. Should heavy rainfall occur, the high flows will soon overtop the trap causing some of the suspended coal residue to be carried to the dirty water dams. Bypass canals, allowing water to flow directly into the pollution control dams when the water level in the canals exceed the flow capacity of the silt trap are therefore provided. It is to be expected that silting will occur in the dams with flows arising from extreme rainfall.

4. CASE STUDY 2

The silt trap design used in the second case study is commonly seen in the coal mining industry. Figure 6 shows the layout of the trap.

Design

The dirty runoff system is designed to flow from the washbay through the silt trap before being discharged into the dirty water system. The discharge point is located 2m above the bottom surface level of the trap.

There are some interesting factors to consider with this particular design, namely the capacity created by having the discharge point higher. The estimated volume of silt that could be settled in this pond is 140m^3, which is of a similar capacity to one of the bays in the trap shown for case study 1, however, this trap takes up considerably less space.

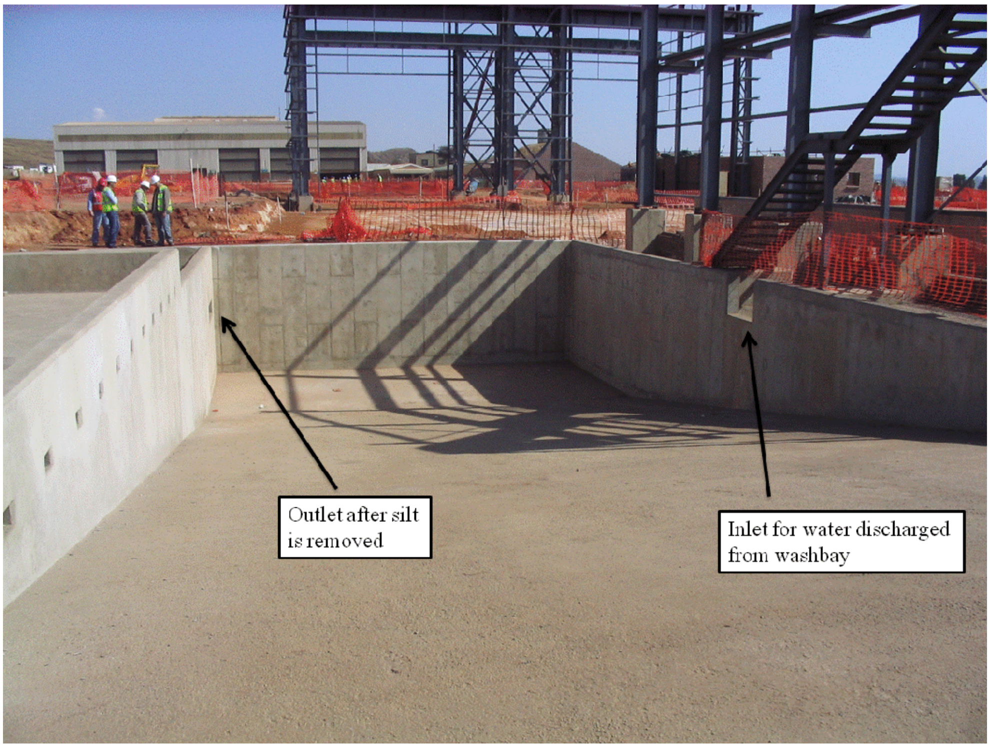

Figure 6. Design of silt trap for case study 2

Trap Efficiency

The different design layout used this case study as apposed to case study 1 will result in different flow characteristics of the contaminated water. While the first design took into consideration a long and flat design, this trap is short and deep. The trap efficiency will remain high granted that the trap is cleaned out regularly.

The key issue in keeping the trap effective with this design will be maintenance. If the trap is left unmaintained, the entire basin capacity will eventually fill up with silt, resulting in a blocking of the discharge channel and eventually blocking the inlet drain.

Maintenance

A TLB is one possibility to be used for the removal of the settled particles. This however could result in practical difficulties as the TLB moves deeper into the silt, and a front end loader or larger machinery may be necessary. Alternatively, a mechanical system (such as slurry pumps) could be installed in order to remove the settled materials from areas where the machinery cannot reach.

Another consideration is that during maintenance and cleaning out of the trap the water containing suspended particles cannot simply be diverted to another bay as in Case study 1, and therefore not allowing time for the silt to partially dry out before being removed.

5. CASE STUDY 3

The silt trap shown in Figure 7 was, as with case study 2, designed in order to contain the silt in the runoff from a washbay. The contaminated water enters through the inlet and then flows gradually through the shallow area, allowing enough time for the suspended particles to settle below the outlet level. The discharged water then enters into a chamber and is pumped to be discharged in the canal above as shown in the figure. The trap was designed such that the depth of the sludge does not exceed the axle of a front end loader. The trap can accommodate approximately 45m^3 of silt at capacity, being designed for small flows from daily dirty water make generated by the cleaning of mine vehicles and not runoff from storm events.

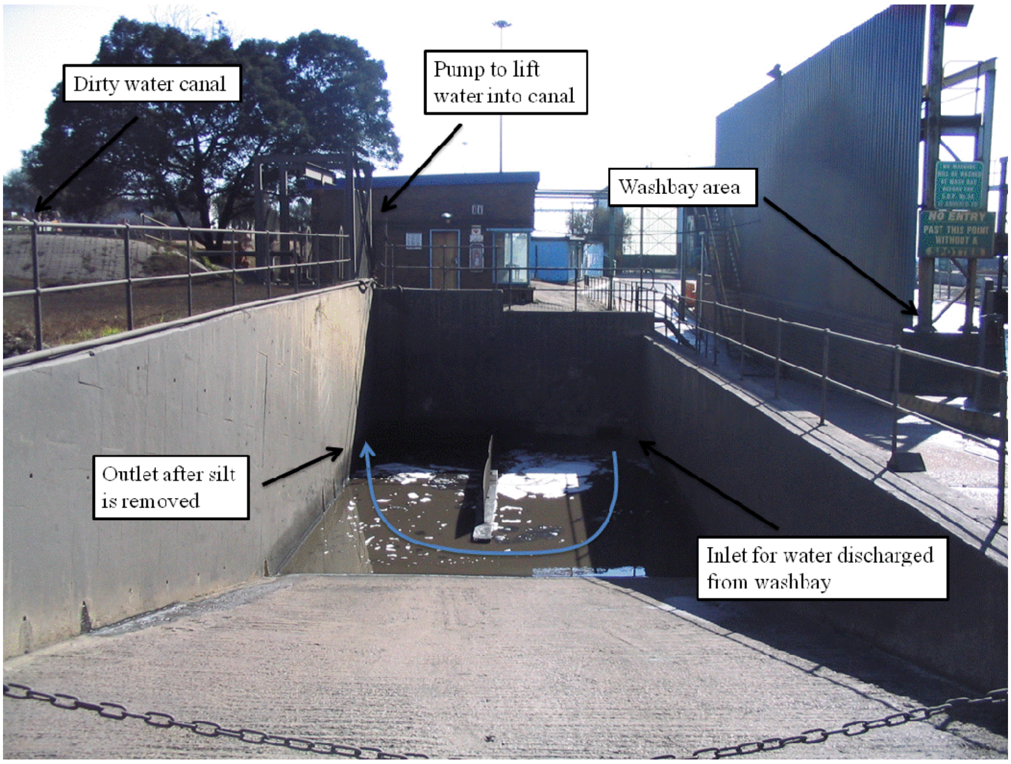

Figure 7. Layout of silt trap for case study 3

Trap Efficiency

The trap, as with case study 1, has been designed based on the theory that the particles are given enough time to settle from their suspended state before reaching the outlet.

Maintenance

This trap, which has been operational for 4 years, is seen as successful from the mine's perspective. The trap remains effective and removes enough silt to avoid significant silting up of canals and pollution control dams. After discussions with management of the mine, it was established that the key to the success of this particular trap is maintenance. It is cleaned out bi-weekly, which allows continuous flow through the trap and ensures that blocking up does not occur.

A comment was noted about the angle of the ramp used to clean the trap. The existing trap is design with a 17 degree slope on which some machines seem to have trouble. Ease of access for cleaning out equipment is an important design factor to consider for silt trap designs.

6. ALTERNATIVE SOLUTION

The case studies shown illustrate the workings of sediment control measures, i.e. the use of silt traps requiring regular maintenance in order to ensure the traps remain operational and efficient. Another possibility is the construction of a settling facility with enough capacity such that the deposition of the residue is allowed for over the design life so that regular cleaning out is not required. Figure 8 shows an example of this type of design. The dirty runoff generated from mining is initially sent to the settling facility where it is then discharged into the dirty water dam. In order to avoid the silting up of the dam, attenuation and settlement time are still important design considerations to ensure a high efficiency for the facility. A clean water canal had been constructed to divert the clean runoff around the dirty water areas.

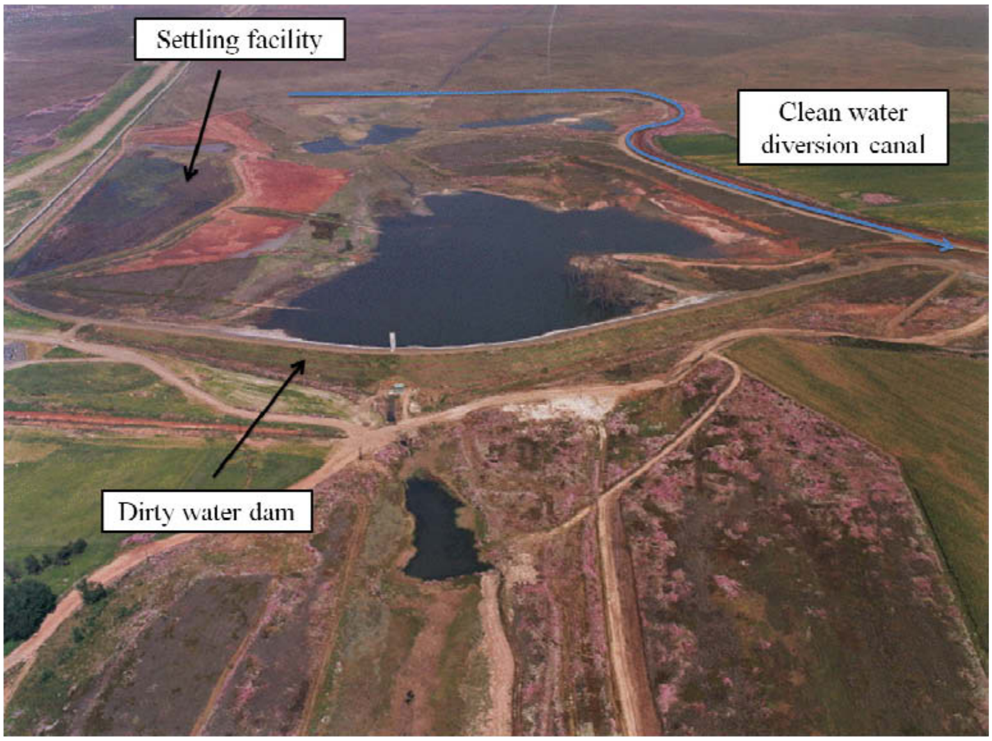

Figure 8. Settling facility and diversion canal

The advantage of this design is that the continuous removal of settled coal residue is not required; however, active management of the system is still necessary i.e. raising of penstock rings as the level of silt rises. The disadvantages, however, would be the cost involved in the construction of the facility due to the greater capacity, as well as a larger area being required.

An important input in the design process is a careful assessment of the silt loading that is expected over the design life. An underestimation will result in costs being occurred at a later stage to either build a new facility or undertake the difficult task of clearing the silt from the existing facility. An overestimation, however, will result in a greater initial capital cost up front on an already expensive solution.

7. CONCLUDING REMARKS

The design of a system to remove the suspended particles from dirty water runoff is relatively simple, with the following parameters being taken into consideration:

- Volume of dirty runoff passing through the trap.
- Rainfall recurrence interval that the silt trap should be able to accommodate.
- Velocity at which the runoff enters and passes through the trap
- Silt load expected
- Particle size distribution expected to be settled in the trap.
- Access being made available for maintenance.

The design engineer would need to assess the above criteria and determine which type of settling facility will be suited to the client's needs and the conditions found specific to each site.

Shown in the investigation of a number of options, there seems to be two general design philosophies for the removal of coal residue from the dirty runoff, namely the conventional system by means of a silt trap and the use of large settling facility as shown in the alternative solution. Each design philosophy has distinct advantages and disadvantages, these are summarised in the following points:

- **Initial capital cost** – the large settling facility will require a high capital outlay, while the use of the conventional silt traps are more economical.
- **Operating costs –** operating costs for conventional traps could be high as regular maintenance is required.
- **Area required** – the area used by conventional traps varies depending on the type of design, but will still be considerably less than using a large settling facility.
- **Regularity of maintenance** – some, but minimal maintenance will be required for the large settling facility. Regular removal of silt is required for the conventional traps.

Through the assessment of different options used for sediment control measures the question still remains: using simple design criteria based on sound principles and theory, why then are so many of these traps perceived to fail? During interviews with design engineers and project managers on mines the word that resounds through all discussions is maintenance. Careful consideration needs to be taken in the design as to the regularity of maintenance that the mine can practically achieve. Location is another important factor as traps that are visible and close to the workings have a better chance of being noticed and regularly cleaned out; together with this a person at the mine being responsible for the effective management of each trap. All the alternatives of settling facilities investigated in this paper will require active management and some level of maintenance through the design life in order to keep these traps functioning in a way that will be beneficial in the long term.

8. REFERENCES

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