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Potential Management and Rehabilitation Requirements of Environmental Effects From Longwall Subsidence on Streams, Lakes and Groundwater Systems

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POTENTIAL MANAGEMENT AND REHABILITATION REQUIREMENTS OF ENVIRONMENTAL EFFECTS FROM LONGWALL SUBSIDENCE ON STREAMS, LAKES AND GROUNDWATER SYSTEMS

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ABSTRACT: Following a series of highly publicised environmental issues relating to subsidence of rivers, streams, lakes and other surface water bodies, as well as groundwater systems, the longwall coal mining approval and environmental management process in NSW now has a significant focus on predicting, monitoring, managing and rehabilitating adverse effects on surface water and groundwater systems.

Due to the recent public and regulatory focus on the issue, future longwall layouts and approvals may be required to demonstrate that unacceptable effects will not be imposed on rivers and streams. This may result in significant changes to panel layouts, or if no acceptable management and rehabilitation measures are available, the worst case scenario may occur where an environmentally sensitive water body may not be undermined.

The range of environmental effects that have been directly observed by the author, as well as reported effects, or effects that could be anticipated from subsidence in NSW coalfields are outlined. Measures required to assess the potential effects on environmental systems, potential rehabilitation requirements, potential risk assessment and management procedures relevant to water related issues are discussed.

The effects of longwall subsidence are outlined for a range of geomorphological areas, whilst an indicative process that can be used to assess the potential severity of effects on surface water and groundwater systems, which leads to the degree of attention required to manage them, are described.

INTRODUCTION

Currently, environmental issues relating to subsidence are managed by approvals under either Section 138 of the Coal Mines Regulation Act 1982, and / or development consent attained through the Environmental Impact Statement process.

Significant changes in community and regulatory attitude requires longwall mines to improve the environmental management of subsidence to conform to NSW Government interagency requirements, as well as concerns of the wider community and other stakeholders. This has generated an enhanced need for responsible resource recovery, with a focus on the reducing impacts on surface water and groundwater systems, improving land use "functionality" and reducing adverse effects on the environment and local communities.

The New South Wales Department of Mineral Resources (DMA) is in the process of formalising and initiating a new longwall extraction approval and management process through "Subsidence Management Plans" (SMP), which will, in turn, replace the current S138 system. The SMP process will involve a greater focus on community consultation, interagency (Departmnet of Land and Water Conservation (DLWC), Evnironmental Protection Acency (EPA), National Parks and Wildlife Service (NPWS), Planning NSW, SCA, NSW Fisheries) and NGO involvement in approving extraction of coal by longwall operations.

The SMP system will be implemented for the life of the approval (potentially up to seven years), and will involve issues such as ongoing community consultation, regular reporting to the DMR and potential revision of operating approvals and conditions as the mine proceeds. The SMP will involve a greater focus on improved subsidence prediction, environmental risk assessment and risk prioritisation in regard to surface water and groundwater that may be adversely affected by subsidence.

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The following surface water and groundwater issues may potentially be addressed;

- Incorporating community concerns during mine planning and approvals process, as well as ongoing community consultation
- Development of risk management plans for sensitive or important environmental features
- Enhanced monitoring, reporting and review programmes
- Incorporation of monitoring, mitigation and rehabilitation of subsidence effects in mine planning, as well as operational and post mine closure situations

The SMP process will require characterisation of natural features such as streams, rivers, groundwater systems, wetlands, swamps, lakes or escarpments along with at least one years baseline monitoring for relevant issues in environmentally sensitive areas.

In addition, non "environmentally" sensitive areas that may be affected, such as farm land will also require assessment of potential changes to the "functionality" of the land. Functionality refers to land holder concerns regarding operating on the land, such as access to creek crossings or groundwater supplies, as well as ponding and erosion of stream bed and banks, cattle access to water, damage to fences and gates, changes in drainage patterns to name a few.

Water related issues to be addressed in a SMP are;

- land use property identification and ownership;
- inventory of watercourses, wetlands, aquifers, water-related ecosystems, forests, cliff lines and other sensitive features in the subsidence area;
- survey of drainage channels within the mine subsidence area and description of base line surface water and groundwater systems and water quality;
- inventories of surface infrastructure and other man-made features within or adjacent to the area which is subject to the SMP, including but not limited to dams, bores, tanks, sprlngs, water reticulation systems, on site waste water systems, swimming pools, and sewerage systems;
- comprehensive subsidence predictions of the relevant surface water body, taking into account topographic variations and geological complexities;
- pre-mining base-line monitoring of ground and surface water flows, water quality and water dependent ecosystems, based on at least a twelve-month survey;
- assessment of potential impacts on water quality, river or groundwater flows and areas that will potentially be drained, inundated or affected by cliff falls;
- descriptions of lake foreshores and flood prone areas;
- outlining significant ecological values of surface water and groundwater systems in the area;
- agricultural or other businesses that may be adversely affected;
- feasible mitigation and remediation measures to reduce and/ or rehabilitate subsidence impacts on significant natural features and ecological values;
- costs (including production foregone, delays, and added costs) associated with various mitigation, remediation or surface feature protection options;
- investigation of other options if subsidence impacts cannot be reduced satisfactorily, such as compensation, acquisition, temporary relocation, or agreement with landowners; and
- identification of all areas of potential compensable loss under the Mining Act 1992 and either reach agreement with landowners in regard to likely compensable loss, or determine suitable mitigation measures to minimise compensable loss.

SURFACE WATER

There are a number of water related features and issues that may be affected by longwall subsidence.

Loss of Surface Water

The dominant environmental impact noted from subsidence is the reduction in surface flows or changes in surface water depths over subsided rivers, streams, upland swamps, wetlands, lakes or farm dams. The loss occurs due to cracking the bedrock beneath a surface water body, with the severity depending on a wide range of associated factors, such as the;

- ephemeral or perennial nature of the water body, with a lesser chance of observable loss during dry periods;
- transfer of surface water into the underlying mine, particularly for mines less than 100m to 130m below the surface. Some mines in the Newcastle field use the algorithm of 45T + 10m (T = seam thickness) to assess if there is a potential for interconnection of a surface water body and the underlying mine. A 2.5m thick seam, for example, could potentially have surface water inflows for a depth of cover less than 122.5m;
- location of the subsidence area in the catchment, with lower order streams (which are higher in the catchment) generally having a less observable water loss compared to higher order, lower catchment streams;
- position of the stream or water body over the tensile or compressive zones of the subsidence trough. Greater water losses occur over the tensile zones at the outer edges of subsidence troughs due to the greater development and interconnection of cracks.
- depth and type of sediment in a stream, wetland, swamp, lake or dam bed. Greater depths of clayey content soils have a higher capacity to self seal the cracks, compared to shallow sandy, or exposed rock at the base of a water body
- mineralogical nature of the sediment. Sediments with a higher clay content and lower dispersivity have a better potential to seal cracks underneath a surface water body compared to higher permeability, sandy sediments;
- outcrop of bedrock. Areas of outcropping bedrock have a higher potential for surface water loss as the orders of magnitude increase in bedrock permeability due to subsidence cracking, is not reduced by infilling from sediments
- relative inflow to the subsided zone compared to the hydraulic conductivity of the sediment / bedrock. Total loss of surface water will occur where a surface water body has an inflow rate below the volume that can flow out through the cracks. A range of variations from total to no loss can occur, depending on the relative inflow and outflow losses to the system.
- Losing or gaining streams. A “losing” stream is where the surface water is higher than the regional groundwater table, and the water “falls” into the regional water table from the stream or other perched water body. A gaining stream is one that is recharged by groundwater inflow from the surrounding catchment. Losing streams are more susceptible to surface water losses through subsidence cracking of their substrate, whereas gaining streams may have an enhanced (although of limited duration) flow due to the higher imposed permeability of the catchment draining into the stream or other body.

Reduced Surface Water Supplies

Consumers relying on a surface water body for their water supply can be deleteriously affected if it, at worst, dries up, or to varying degrees, is reduced.

Reduced Water Quality

The reduction in water quality is generally not a significant issue for most mines, except within the Sydney Catchment Authority areas in the Southern and Western Coalfields.

Generally an increase in iron hydroxides can change the water appearance by varying degrees to an orange brown colour. This effect is due to enhanced shallow groundwater flow through fresh fractures partially dissolving iron sulfides (generally marcasite) and iron hydroxides within the fresh bedrock and precipitating the iron at chemical redox phase changes, such as where chemically reduced groundwater with dissolved iron species flows into an oxidising surface water body. The effect is generally more important from an aesthetic rather than chemical viewpoint, however the dissolution of iron minerals can also liberate low concentrations of associated metals. This dissolution and transport of metals is particularly observed for areas draining through shale substrates.

The reduction in water quality or discolouration is generally restricted to areas close to the groundwater discharge or upwelling zones, and does not extend over large areas as the iron hydroxides precipitate and settle out near to the discharge area.

Stream Bed And Bank Erosion

Bed and bank erosion due to subsidence can have significant effects on stability of streams. This is particularly noticed on the upstream section of a subsidence troughs as headcuts can be generated in a stream bed that can migrate for hundreds of metres upstream if not managed appropriately. The degree of bed and bank erosion depends on topographic changes endured by the stream, as well as the

- clayey or sandy nature of the stream bed and banks,
- soil dispersivity,
- height of stream banks,
- degree of destabilisation of the banks
- orientation of the stream to the subsidence trough
- seasonal or storm water flow variability
- logs, crossings, culverts or other features that can divert or confine flows
- bedrock in the stream bed, and
- interaction of tensile stress zones with stream banks

The stream attempts to resurrect its original gradient and stability regime after a subsidence trough or troughs intersect it. The adjustment generally takes the initial response of cutting down the stream bed over chain pillars and filling in subsidence troughs. Relocation of flow paths within the channel can erode the stream banks, whilst the headcut gradually migrates upstream. Without bed and bank erosion protection, the stream can adjust to a new regime over many years, with significant extension of the bed width and elongation of the headcut.

Adverse Ecosystem Changes

Ecosystems dependent on the stability or seasonal variation of a particular surface water body can be significantly affected by subsidence, particularly in the worst case where the water body is drained dry. Other effects that may occur are;

- Loss of ecosystem interconnection and potential transfer / replenishment of species. This is particularly noticeable where seasonal fish migration is affected by drying up of stream sections due to mining induced water loss.
- Changes in water temperature, dissolved oxygen, turbidity, and algal growth. The alteration of water depth, recharge versus discharge and the residence time in a body of water can significantly affect the health and diversity of a surface water body.

Reduction in Cropping or Grazing Land Functionality and Productivity

The "functionality" of cropping or grazing land can be affected by development of subsidence troughs and soil cracking diverting or collecting surface runoff, along with associated erosion or saturation of ground with a greater potential for bogging machinery. Other aspects of functionality can be present such as modified cattle access to streams, submerged or modified creek crossings, cracking of dams, and surface water ponding.

Subsidence effects on the wheat cropping potential of subsided land are being studied for an ACARP research project in the Bowen Basin by the Centre For Mined Land Rehabilitation. Although the project is not completed, initial indications are that the crop is not significantly affected. Overseas research, however, has indicated that cropping productivity is adversely affected

Diversion of Stream Flow Lines and Ponding

Drainage patterns of streams may be affected by diversion of flow out of the original channel. This may occur where subsidence troughs are not parallel, or indeed, perpendicular to the stream channel, with the drainage taking a preferential path along the subsidence trough. In some cases, particularly where the remnant ground height over chain pillars between subsidence troughs is higher than the banks of the stream, the stream may be dammed at the chain pillar and diverted along the trough.

Ponding of water in subsidence troughs can occur in paddocks or it can cause deepening and widening of pools in a stream, which if not filled in with subsequent sediment movement can lead to alteration of riparian ecosystems and geomorphological stability of the area.

Breaching or Dewatering Farm Dams

Breaching and /or dewatering of farm dams is possible due to subsidence crack development either in the walls or floor of farm dams. This may cause either a gradual loss of water or short term "catastrophic" outflows which may be a danger to people, animals or vegetation communities downstream of the dam.

Subsidence of Lake Shorelines

Subsidence of lake shorelines has been noted in the Newcastle Coalfield, where significant beach stabilisation and rehabilitation have been required.

GROUNDWATER

Dewatering or Interconnection of Aquifers

Subsidence and associated bedrock cracking over longwall panels can result in either dewatering of shallow aquifers separated by underlying aquitards which can in turn drain to the mine to underlying aquifers, or both. Development of cracks in the overburden can also allow deeper aquifers under high head to rise up into shallower aquifers.

Groundwater supply bores or monitoring piezometers can be significantly affected by lateral shearing of the bedrock, essentially by cutting the bore / piezometer off, which may necessitate a new water supply bore to be drilled to re-establish the water supply.

Reduction of the groundwater table may be permanent, in the case where groundwater drains into the mine or some other discharge feature, or temporary if the water level falls due to groundwater filling the increased secondary porosity of the bedrock due to development of new cracks. Once the new voids are filled, and on the assumption that there is no outflow from the regional system, the groundwater table will resume its original level. This recovery depends on the rate of recharge, with slower recoveries during drought periods.

The effect of dewatering may be temporary, as has been observed in the plateau country in the Southern Coalfield, but in some cases, a temporary water supply is required to replace the lost groundwater supply.

Reduction in Spring Flow and / or Stream Baseflow Recharge

The location and flow rate of springs in hillsides can be affected by subsidence cracking. This can occur if a spring is located on a hill due to the presence of an underlying aquitard limiting vertical migration of recharge through overburden. If the aquitard is breached, the spring may dry up or have its discharge rate reduced, with an associated flow increase to springs further down the slope.

Groundwater baseflow to streams can also be affected, with either an increase or decrease in discharge rate to streams, as well as a shortened response time to recharge and discharge. Higher discharge flow rates may occur due to the enhanced permeability of the aquifer due to crack development, however the duration of flows may be shortened as the aquifer drains out faster.

Emergence of the Groundwater Table

Groundwater in shallow aquifers can "daylight" if the depth of subsidence exceeds pre mining standing water levels over mined out panels. In this case, the ground level falls to a lower RL within the subsidence trough, whereas the water table remains at the same pre mining RL as its level is determined by catchment wide, rather than localised factors.

Flows into mine

Significant adverse health and safety issues can develop in mines where subsidence goaf and surface cracking intersect, thereby allowing aquifers in the overburden, streams flowing over the subsidence area or overlying lakes, dams or ponds to drain directly and rapidly into an underground mine.

This can generate a significant safety hazard to workers in the mine if catastrophic inflows occur whilst the mine is occupied, whilst ongoing inflows can cause a significant requirement to pump out excess water from the mine.

Interference effects from adjoining mines

Temporary or long term depression of groundwater tables over subsided longwall panels can interact with adjoining open pit or underground leaseholders effects on the regional groundwater system, or alternately, adjoining operations can reduce standing water levels in a longwall lease.

Seam or Overburden Gas Discharge to the Atmosphere

Hydrocarbon gas comprising predominantly methane discharging from recently mined coal seams, or fractured overburden can vent to the atmosphere via interconnecting fractures, and / or through piezometers or wells within the mine subsidence fractured zone. This discharge can significantly disrupt water levels within the piezometer / well and cause temporary dewatering as it is "airlifted".

This effect lasts as long as it be for the gas to vent off, which can take a few weeks to months.

MANAGEMENT AND REHABILITATION OF ADVERSE CHANGES TO SURFACE WATER AND GROUNDWATER SYSTEMS

The interrelationship of environmental issues described can, in some cases, be managed or rehabilitated by the same method. For instance, limiting water loss from a stream and reducing inflows to a mine close to surface can be achieved by sealing a stream bed and banks over the subsided section. This has been achieved to date primarily by either cement injection grouting of bedrock under a stream or rock pool or by sealing the channel with a compacted clay blanket buried beneath the sediment scour depth.

Reducing water losses from the stream or pool also has the advantage of enabling re-establishment of water dependent ecosystems and improving water quality in the affected area. Cement or clay based methods used to reduce stream flow losses do not, however, address stream bed or bank destabilisation and erosion, ponding of water or emergence of shallow groundwater.

Stream flow or water depth losses can also be rehabilitated by introducing compensatory inflow, such as treated town water, mine water or other inputs with acceptable water quality.

Rehabilitating bed and bank erosion may require a range of earthworks and sound erosion protection techniques that are designed to achieve specific outcomes. Each situation requires a specific remedy, or combination of rehabilitation approaches.

Management of headward bed erosion due to a stream cutting back or filling induced undulations over chain pillars and subsidence troughs generally involves installation of buried, keyed in rock weirs at the point of headward erosion. A stream cutting down a channel over a chain pillar will deposit sediment in the subsidence troughs as it attempts to re-establish its original gradient, however significant downstream discharge of suspended sediment may occur in the process. These sediments may need to be restricted from moving by additional sediment collection weirs. In perennial streams, weirs may also need to account for fish passage.

Stream bank erosion can generally be controlled by regrading the streambank and revegetating the area after installing fences to keep out cattle. Cattle can have a significant deleterious effect on bed and bank stability, with or without the added effect of subsidence.

Water quality can be improved by dilution with a suitable rate and quality of input supply, however iron hydroxides formed through upwelling of ferrous iron laden groundwater cannot be stopped unless the groundwater recharge / discharge relationship can be managed. Generally, the iron hydroxide concentration reduces over time, as the bedrock cracks become oxidised over months rather than weeks.

Adverse effects on cropping or grazing land through soil cracking and subsidence can be rehabilitated by deep ripping the cracks, however diversion of flow lines or water ponding may require additional drainage works, with the works planned and implemented in consultation with the DLWC.

Leaking or breached farm dams can be rehabilitated by resealing the dam wall and base and or building up the wall to an appropriate level.

Little can be done to rehabilitate dewatered aquifers or the interconnection of aquifers, as the subsidence crack development extends over the entire subsidence area, and grouting the overburden is generally not economically or logistically viable. Adverse effects on spring flow or groundwater stream recharge is also difficult to rehabilitate, except to provide suitable compensatory inflows.

Emergence of the groundwater table is also difficult to rehabilitate, unless the area is backfilled and rehabilitated to its original height, with this option having its own set of difficulties.

Groundwater flows into a mine can be significant, dangerous and costly. Inflows may be high for an initial period depending on the connectivity of the aquifer, its transmissivity, recharge and other factors, however over time, flows generally decrease as the aquifer is dewatered.

REFERENCES

Waddington Kay & Associates et al, 2002 Management Information Handbook on Undermining of Cliffs, Gorges and River Systems, Australian Coal Association Research Program Projects C8005 and C9067

Mine Subsidence Technological Society, 2001 5th Triennial Conference Proceedings Maitland August 2001

Issue	Management Option
SURFACE WATER	
Loss of Surface Water Flow / Water Depth	Cement, cement / bentonite grouting
	clay seal sediments below scour depth
	Fill in cracks with sediment / clay
Reduced Surface Water Supply	Provide compensatory input by increasing upstream flows, trucking in water or installing other water supplies
Reduced Water Quality	Dilute the affected water with additional fresh supply
	Water treatment
	Re-establish flows to their original state
Stream Bed and Bank Erosion	Battering back banks, installing headward erosion control weirs, and protection of eroding banks
	Fence off affected area and establish riparian vegetation
	Exclude cattle
Adverse Ecosystem Changes	Re-establish the original water flows, depths, water quality if possible
Reduced Land Functionality or Productivity	Deep rip cracks, fill in subsided areas,
Diversion of Stream Flow Lines or Ponding	Install levees, or excavate drainage paths for collected water
Breaching or Dewatering Farm Dams	Reseal dam wall or floor with clay, and reform wall in extreme cases to original state
Lake Shore Subsidence	Rehabilitate the lake shore as appropriate
GROUNDWATER	
Dewatering or Interconnection of Aquifers	Not much can be done on a mine scale, however isolated areas could be grouted at very high cost
Reduced Spring Flow or Stream Baseflow Recharge	If possible, re-establish the original aquitard seal under the aquifer (expensive and logistically difficult)
Emergence of Groundwater Table	Fill in isolated subsided areas
	Establish a groundwater extraction programme
Flows into a Mine	Seal the overburden by grouting, or divert surface water from over the mine
Interference Effects From Adjoining Mines	No cost effective options used to date
Seam Gas Discharge to the Atmosphere	Plug wells and piezometers, or wait for gas flow to abate