A review of the effect of floodplain gravel mining on river stability

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Key Points

- A large amount of aggregate is used in advanced economies such as Australia; 6 to 12 tonnes per person per year. Some of this aggregate is supplied from floodplain mining
- Floodplain gravel mining is seen to be safer than direct extraction of gravel from rivers but there remain substantial threats to river stability
- A literature review found 37 examples where rivers had broken into gravel mines and the resulting river response had led to bed and bank erosion and threats to infrastructure.
- Appropriate locations for, and active management of, floodplain gravel mines is required to reduce threats to acceptable levels and ensure the sustainability of mines

Abstract

Floodplain gravel mining can cause change in the riverine environment, both locally and distant to the mining site, and in the short and long term. Immediate effects of mining include loss of land and vegetation and other impacts such as noise, dust and vibration. Gravel mining may affect flood hydraulics. During floods, gravel pits provide an area of increased conveyance to flow and often a shortened flow path for floodwaters. This can result in high velocities and scour. Erosional processes associated with floodplain pits can result in river channel changes where the river diverts into, and through, gravel mines. This can lead to bed degradation, bank erosion and channel widening. Infrastructure may be damaged or destroyed. Riparian vegetation and habitat may be damaged and in-stream habitat degraded. Local, national and international case studies show that pit capture and subsequent river channel changes, are a common consequence of floodplain mining. There are at least 37 documented examples where rivers have diverted through mining pits. The risk of pit capture is greatest were mines are deeper than the adjacent river bed and close to the river. Risks to infrastructure increase with proximity to mines.

Keywords

Floodplain mining, gravel mining, river stability

Introduction

Modern societies in developed countries use large amounts of aggregate; commonly 6 to 12 tonnes per person per year (Robinson and Brown, 2002; UPEG, 2010). Aggregate makes up 80% of concrete and 90% of asphalt pavements so is a key input to the construction industry.

Direct extraction of gravel from rivers has been a common source of aggregate although adverse impacts on river stability are now well known (Dunne and Leopold, 1978; Kondolf,1994; 1997; Rinaldi et al., 2005). To reduce these impacts, one response from river managers has been to shift gravel mining operations from rivers to floodplains. In this paper we review the threats from floodplain mining operations and show that many river values remain at risk. These risks need to be controlled or mitigated to be kept at tolerable levels.

Risks from floodplain gravel mining

There are risks associated with floodplain gravel mining, both immediate and longer term (New South Wales Government, 1992; Norman et al., 1998; Langer, 1999; Kondolf et al., 2002).

Immediate implications of floodplain gravel mining

During gravel mining, the immediate area of the mine will be affected by impacts that include:

- Loss of agricultural land
- Loss of riparian vegetation and riparian habitat
- Loss of floodplain habitat
- Increases in noise and dust
- Disturbance of heritage values
- Disturbance of cultural values
- Potential concern related to impacts on rare and threatened species
- Changes in aesthetics, particularly a change in scenic quality.

Standard planning approaches are in place to address many of these concerns. Examples of these approaches include:

- Cultural Heritage Management Plans
- Processes under the *Environmental Protection and Biodiversity Conservation Act 1999* (Cwth) to consider threatened species
- Processes under the *Flora and Fauna Guarantee Act 1988* (Vic) which are managed by the Department of Environment and Primary Industries
- The native vegetation management framework
- The Victorian Planning Provisions (particularly clause 14)
- Local government planning processes
- Local government and EPA processes for considering noise, dust and vibration
- Processes for considering water use, contaminated runoff and groundwater impacts and impacts on waterways.

There is a role for river management authorities to inform the decisions made by others particularly in relation to river health and stability and catchment management issues associated with gravel mines.

Delayed impacts of floodplain gravel mining

The delayed impacts of floodplain gravel mining are more severe and are generally not well regulated. These impacts include:

- The low resistance flow high flow conveyance path provided by the open area of a gravel mine can alter floodplain hydraulics during high flows
- Stockpiles of overburden and gravel on the floodplain may divert or change flow paths under flood conditions and may lead to water quality issues and downstream sedimentation (Follman, 1980)
- Mining on floodplains may reduce groundwater levels on adjacent areas where water is removed by pumping and may affect groundwater quality (Hatva, 1994; Langer, 1999)
- Floodplain mines may lead to river channel changes that include erosion, bed degradation and damage to infrastructure.

Floodplain hydraulics

Gravel mining affects flood hydraulics. Gravel pits are often leveed to restrict entry of floodwaters which will reduce floodplain storage and the area of the floodplain available for flow. This may increase flood levels and velocities in other areas of the floodplain. If floodwaters impinge on stockpiles, material, particularly fines, may be dispersed leading to sedimentation and water quality issues.

If floodwaters have access to mine areas, the gravel pit will present an area of decreased flow resistance. This low resistance combined with pit geometry, which often results in a shortened flow path for flood flows, will increase hydraulic conveyance, and lead to hydraulic drawdown and subsequent acceleration of flow towards the pit. These hydraulic conditions cause the sediment transport capacity of the flow to increase above the incoming rate of sediment supply, resulting in erosion (e.g. Galay, 1983). Local turbulent flow around obstructions such as trees on the bank of extraction pits could also initiate knickpoints that develop into avulsions (Gibling et al., 1998; Tooth and Nanson, 1999). Pits can also initiate avulsions through other failure mechanisms:

- lateral migration of the river channel into the pit
- sub-surface piping from surface water into pits and subsequent failure of pit walls
- water cascading into a gravel pit as flood waters rise
- erosion by water returning to the river from the pit as the flood recedes.

These failure modes are explored further when discussing case studies.

Groundwater

Floodplain mining converts riparian land (agricultural land or areas of native forest) into open pits which typically intersect the groundwater table (Kondolf, 1997). Gravel operations will affect groundwater levels because water will evaporate from open pits or, water may be pumped to facilitate extraction. Dry operations, where material can be directly removed by earth moving equipment, generally result in a lower cost of extraction than dredging. Mining may also result in contamination of pit water which may then cause contamination of groundwater.

In Victoria, the State Environmental Protection Policy requires the prevention of groundwater pollution. If groundwater is to be pumped from a mine, approval is required from the relevant rural water authority.

Risks to river stability: case studies

Significant impacts can occur if gravel mining leads to river channel changes including bed degradation, bank erosion and channel widening. Infrastructure may be damaged or destroyed.

An indication of the potential risk of floodplain gravel mining can be determined by reviewing local, national and international case studies of similar operations. These case studies exhibit a variety of impacts and failure mechanisms. Documented examples include the following:

- Floodplain gravel mining on the floodplain of the Goulburn River, Victoria led to the capture of a tributary, Island Creek. This caused a knickpoint to progress upstream which undermined and toppled mature red gum vegetation and destroyed a road crossing (Figures 1, 2 and 3) (Craigie, 2012).
- On the Georges River, near Chipping Norton in western Sydney and at Lake Moore (upstream from Chipping Norton), many gravel pits have been captured by the river, increasing tidal velocities and causing channel erosion (Warner et al., 1977).
- The Fish River, near Bathurst, changed course to flow through gravel pits, as did the Nepean River at Castlereagh (Erskine, 1990).
- On the Tangipahoa River in Louisiana, six gravel mining pits (of a total of 56) were captured by the river between 1980 and 2004. Up to 6 m of bed degradation occurred upstream of pit captures, with aggregation

downstream because of increased erosion. A highway bridge failed because of the bed degradation (Mossa and Marks, 2011).

- In Southern California, bed degradation of 4 m was caused when floodwaters entered a gravel pit 15 m to 23 m deep on a formerly inactive branch of the Tujunga Wash. Three bridges and seven houses were destroyed (Scott, 1973; Bull and Scott, 1974).
- Floodplain and in-channel mining on the San Benito River in California, led to 3 m of bed degradation, channel widening, loss of one bridge and damage to two others. City water and sewer mains required replacement (Harvey and Smith, 1998).
- The change in alignment caused when the Stony Creek (California, USA) broke into a gravel pit, caused local scour around the bridge piers of Interstate Highway 5, necessitating repair (Kondolf and Swanson, 1993).
- In northern Alaska, 12 of 25 floodplain gravel pits studied by the US Department of the Interior had resulted in flow diversion, or the high potential for diversion, through the pits (Rundquist, 1980, p95).
- A review by Norman et al. (1998) found that in the 14 years between 1984 and 1998, 11 floodplain gravel pits in Washington State had captured river flow. One example is the Cowlitz River where flow into a gravel pit led to a river avulsion.
- On the Clackamas River at Clackamas, Oregon, an avulsion into a gravel pit caused river bed degradation of 2 m, 500 m upstream of the pit (Kondolf et al., 1996).
- The Rogue River, Oregon, changed course into a gravel pit which resulted in erosion and loss of a tower for a power line across the river (Klingeman, 1998).
- In their review of aggregate mines on the Lower Merced River (California, USA), Kondolf et al (1996) found that the river had diverted through 8 gravel mines that were excavated on the floodplain or point bars.
- The Yakima River (Washington, USA) shifted course to flow through gravel pits near Yakima and threatened an interstate highway (Dunne and Leopold, 1978).
- Floodplain gravel mining on the Jarama River in Spain has caused the river to straighten because of diversion of the river through gravel pits (Uribelarrea et al., 2003).

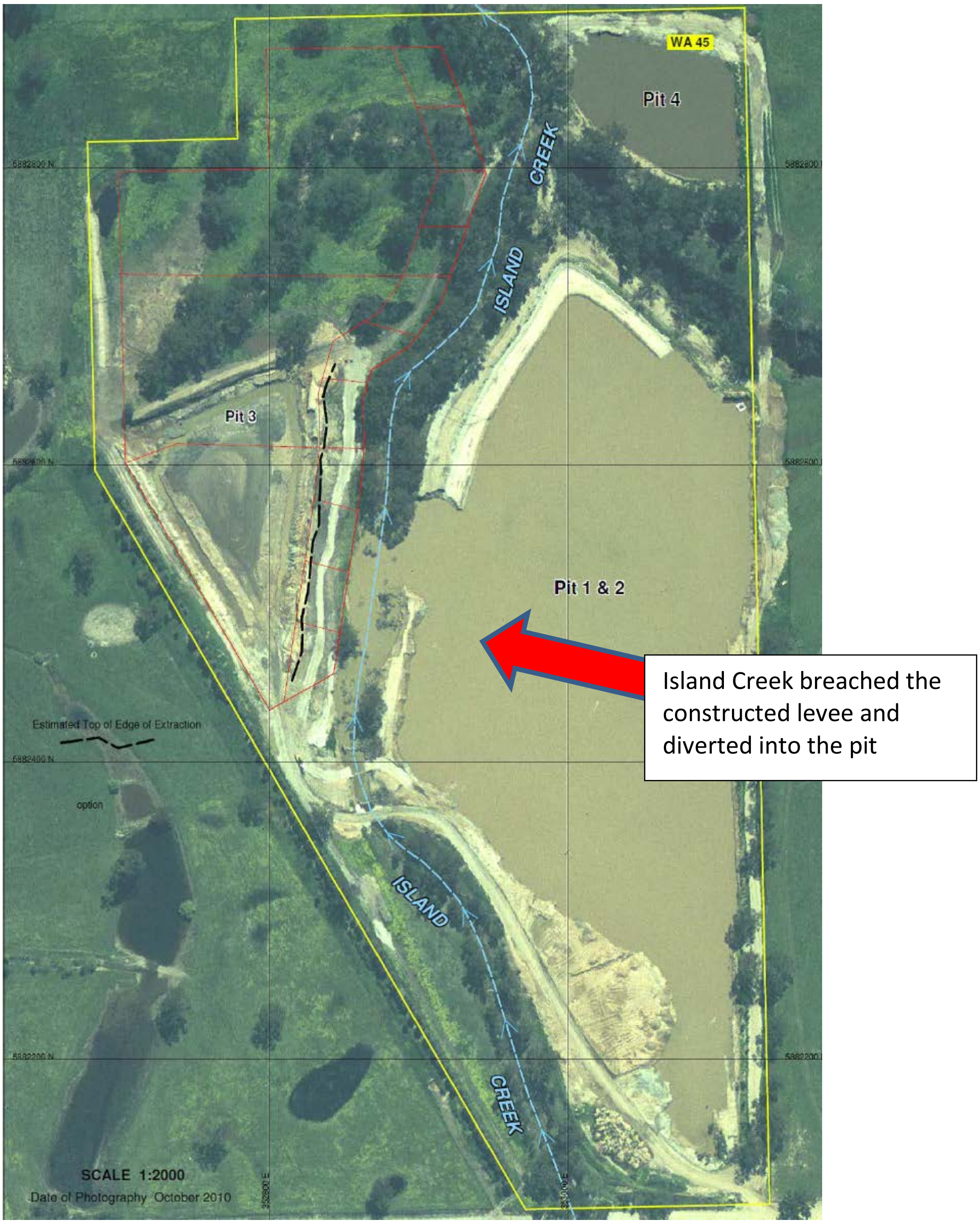

Figure 1. Diversion of Island Creek into a gravel pit on the Goulburn River floodplain (Craigie, 2012)

Figure 2. Upstream progressing erosion caused when Island Creek broke into a gravel mine on the Goulburn River floodplain (Craigie, 2012)

Figure 3. Road crossing in Figure 2 destroyed by bed incision which has also toppled riparian trees (Craigie, 2012)

- On the South Platte River in Colorado, 1.2 m of bed incision was caused between 1983 and 1986 by in-stream mining and the capture of a floodplain mining pit (Stevens et al., 1990).
- Pit capture on Blackwood Creek CA, lead to upstream and downstream bed incision and an increase in sediment delivery to a downstream lake (Todd, 1989).
- On the Amite River in Louisiana, Mossa and McLean (1997) showed a statistical link between floodplain mining and channel change.

The risk of stream diversion through pits is increased by:

- Proximity to the river (Mossa and Marks, 2011)
- Increased depth of the gravel pit, particularly where the base of the pit is below the lowest bed elevation of the deepest pools in the river.

The larger the captured pit, the greater is the change in the river (Mossa and Marks, 2011).

Norman et al. (1998) state that in the long term, stream capture by gravel pits is a near certainty. If a stream changes course to flow through a gravel mine, impacts may be similar to those of in-channel mines which include (Norman et al., 1998):

- Lowering the river bed level by erosion upstream and downstream of the mine
- Bank erosion caused by bed erosion
- Increased suspended sediment load
- Changes to aquatic habitat
- Changes to groundwater levels caused by changes in the water surface elevation.

There are a large number of case studies that describe infrastructure damage from in-stream mining (Kondolf, 1994; 1997; Rinaldi et al., 2005). Mossa and Marks (2011) comment that floodplain mining is far less regulated than in-stream mining, even though the geomorphic changes that can occur are generally more dramatic.

Mitigating the risks of floodplain gravel mining

Many of the potential impacts of gravel mining relate directly to the responsibilities of river managers, particularly where gravel mines may affect:

- River health
- Floodplain hydraulics
- Riparian vegetation and habitat
- Loss of in-stream habitat

There may be a role for river management agencies to influence the amount of mining that is undertaken, and the manner in which it is undertaken, in order to mitigate these threats. This is best undertaken through development of a planning framework that provides for sustainable gravel extraction.

In addition to guiding future extractions, the framework needs to consider legacy issues of existing mines and abandoned extraction operations. Further work is required to develop this framework which is likely to require targeted and effective documentation for planning scheme amendments or other regulatory change. It will be necessary to work closely with local government and other natural resource managers to achieve a robust and reliable framework.

There are a number of examples of guidelines and policies for floodplain mining (Woodward Clyde Consultants, 1980; Collins and Dunne, 1990; Erskine et al., 1996; NOAA, 2004; Kondolf, 1998). Approaches in these documents that have been used by others to minimise impacts include, for example:

- Mining features such as terraces that are higher in elevation than the active floodplain
- Protecting stockpiles from floodwaters to reduce water quality risks
- Locating mining pits based on geomorphic and engineering considerations to, for example, provide setbacks from waterways.

There are also guidelines available to improve rehabilitation of exhausted pits. These include:

- Gravel pit restoration for wildlife (a practical manual) (Andrews and Kinsman, 1993)
- Wildlife after gravel: twenty years of practical research by the Game Conservancy (Giles, 1992)
- River restoration and near-channel gravel mining (Klingeman, 1998).

Where pits are deep and steep-sided, they offer limited wetland habitat and stratification may make much of the water body anoxic (Turner and Erskine, 2005). If pits can be rehabilitated through provision of gently sloping banks, irregular shorelines and with appropriate vegetation, they may offer areas of environmental value.

Conclusions

Although floodplain gravel mining has been considered a safer option than the direct extraction of gravel from a river, substantial risks to river stability and river health values remain. Floodplain gravel mining can cause change in the riverine environment, both locally and distant to the mining site, and in the short and long term.

Local, national and international case studies show that pit capture and subsequent river channel changes, are a common consequence of floodplain mining. There are at least 37 documented examples where rivers have diverted through mining pits. There are substantial risks to infrastructure if river diversions occur which trigger bed and bank erosion.

There may be a role for river management agencies to influence the amount of mining that is undertaken, and the manner in which it is undertaken, in order to mitigate these threats. This is best undertaken through development of a planning framework that provides for sustainable gravel extraction.

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Problem Risk	Cause Impact	Response/Action	Relevant Case Study
Loss of Agricultural Land	Pit induced Erosion	Improved Planning	1, 3, 5
⋮	⋮	⋮	
Disturbance of Heritage Values	Inappropriate Location of Pit	Planning Legis	A, B, C.
Removal of Native Veg	Increased erosion, and lateral migration	Staged extraction with Reveg	X, Y, Z

Case Study etc. 1, Niles & Lambert (1983) 2, (Rogers & Hart 1996)