The Potential Impact of Minerals Prospecting on Streams in Victorian National Parks. What can we tell from the scientific literature?

A review conducted for the Victorian Environmental Assessment Council

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Introduction

The Minister for Environment and Climate Change has requested the Victorian Environmental Assessment Council (VEAC) to carry out an investigation into prospecting in specified parks listed under the *National Parks Act 1975*. The overall objective of the investigation is to increase the number of parks listed under the *National Parks Act 1975* where prospecting may be permitted. This review has been commissioned by VEAC to identify, as far as possible, based on published literature and professional judgement, potential impacts that may occur as a result of prospecting in streams in the specified parks.

The time available to conduct the review has been quite limited, which has in turn constrained the literature that could be accessed, and the number of specialists who could be consulted. Nevertheless this document identifies the key issues in relation to streams although it does not constitute an exhaustive literature review.

What are the target areas?

The national parks which have been identified as having areas of substantial interest to prospectors are: Alpine, Baw Baw, Croajingolong, Errinundra, Lake Eildon, Lind, Mitchell River and Yarra Ranges national parks and Lerderderg State Park. Within these parks not all areas, or all streams, are of interest to prospectors. The primary focus is on areas and streams which occur within known auriferous or mineralized areas. These are broadly identified in the maps of each park included in Appendix 1.

What is Prospecting?

Prospecting is defined as searching for minerals or gemstones under a Miner's Right or a Tourist Fossicking Authority as defined in the *Mineral Resources (Sustainable Development) Act 1990*. Prospectors are required to hold a Miners Right, and prospecting is currently permitted in limited areas in several State Parks and in five National Parks, and in two additional National Parks for gemstones only. Prospecting is permitted in rivers, however there is a list of about 300 rivers and other water bodies from which prospecting is currently excluded (http://www.dpi.vic.gov.au/earth-resources/exploration-and-mining/prospecting-and-fossicking/faqs).

The *Mineral Resources (Sustainable Development) Act 1990* sets out the types of activity and constraints which apply to those who engage in prospecting. Prospectors may not use explosives, or remove or damage trees or shrubs, or disturb archaeological sites of Aboriginal places or objects. Only non-mechanical hand tools can be used by prospectors to excavate material, but motorized equipment may be used to process material which has been excavated, and loaded, by hand as long as the equipment does not cause significant land disturbance. Any damage to the land arising from prospecting activities must be repaired. The use of eductor dredges, which would not be classified as non-mechanical hand tools, is not permitted.

Broadly the activities of prospectors in streams would include the hand excavation of gravel and fines from the stream bed and/or banks, which may require moving other material such as organic debris, coarser cobbles or larger rocks to obtain access to the gravel, and then processing the gravel by panning, sieving or sluicing to locate and remove gold, gemstones or other valuable material from amongst the base material. The gravel and fines remaining would then be returned to the stream.

The extent of the area affected and the intensity of the physical impact is a function of the depth, the area and the frequency of the prospecting in a particular stream. The depth of the excavation would be to bedrock where practicable, because that is where the gold tends to accumulate, but the manual extraction methods may limit the practicable depth in some cases. The area excavated will depend partly on the technique employed – for example whether the prospector is using metal detection and only excavating "hit" points, or whether the prospector is excavating larger extents of gravel beds. The other factors influencing the area impacted are the number of prospectors who work a particular locality, and the length of time each one spends excavating. Some recreational prospectors would work only for an hour or two, while other could work for months in a single location. Similarly some stream locations may be prospected only once, or not at all, while others may be prospected repeatedly, possibly numerous times in a year for many years. The frequency of prospecting may vary depending on a wide range of factors such as ease of access, proximity to population centres, reputation as a locality in which gold is often found, or simply being the favourite location for one of more regular prospectors.

What are the physical environmental effects of prospecting in streams?

The physical impacts of prospecting in streams arise from both the excavation and the return of the tailings to the stream.

Impacts from Excavation

Excavation can have a number of different impacts. Removal or moving stones on the stream bed surface may disrupt bed armouring, and reduce the future stability of the stream bed. Armouring is the development of a stream bed surface layer which is coarser than the material beneath. This layer protects the finer sediments beneath during high flow events (Gordon et al. 2004). Similarly excavations from the stream bank may create points of weakness which are susceptible to future bank erosion. Disturbance or extraction of bed material will disrupt organisms living on or among the grains of the material. Some of the organisms may be killed or damaged, others may be washed off or may purposefully drift out from the material as it is extracted. When the material is replaced it will be packed in the stream bed differently, usually in a less tightly packed state, creating a slightly different habitat. In disrupting the armouring, prospecting differs significantly from natural high flow events where armouring normally remains substantially intact.

The removal of material from the bed will also release fine particulate material into the water column. Some of this material, which is normally buried in the stream bed, will be exposed to the current and washed downstream. The material may consist solely of inert sediment, but where there are contaminants, such as mercury or arsenic, present in the sediment and adsorbed to fine particles, the contaminants may also be remobilized and released into the water column.

Impacts from Tailings Return

Tailings are the waste products remaining after gold or other valuable components are removed from the excavated gravel. Because the gold normally constitutes a small fraction of the material excavated, the volume of tailings is almost the same as the volume of excavated material. Normally, with small scale operations such as prospecting, the particle size distribution of the tailings is very similar to that of the excavate. The only difference is likely to be a smaller proportion of very fine particles as these are likely to be washed out during processing, and be washed down stream. If processing includes some sort of rock crushing, as it does for large scale mining, the particle size distribution may be altered. But that would not normally be the case for prospecting scale operations.

When the excavate is processed using stream water the larger particle sized material, such as stones, gravel and sand, will drop out at the immediate processing point. The finer particle material will be carried in suspension for some distance downstream. The actual distance will depend on the size and nature of the particles and the turbulence and velocity of the stream. In a slow flowing stream, or in large slow flowing pools in an otherwise rapidly flowing stream, the particles will tend to settle out in a relatively short distance. Very fine particles, such as clay particles and fine organic particles, may remain in suspension in the water for more than a kilometre downstream (Georgian et al 2003). As with the excavation process, any contaminants that may have been stored in the stream bed attached to the fine particles will be remobilized when the fine particles are resuspended.

Sluicing is commonly used in prospecting. The tailings from a sluice form into a pile below the outlet of the sluice, unless redistributed by the prospector. In smaller streams, the tailings pile may substantially alter the localised physical structure of the stream, at least until the next high flow event.

What components of the stream biota will be exposed to potential impact?

Rivers and streams provide the habitats for a wide range of organisms. They include a variety of microorganisms, including bacteria, fungi and single-celled algae, larger plants (macrophytes), invertebrates such as insects, crustaceans and worms, fish, and mammals such as platypus and water rats (Hynes 1970, Bayly and Williams 1973).

The microorganisms in small streams are mostly present growing in thin layers, referred to as biofilms, on solid surfaces such as stones and logs (Boulton and Brock 1999). Where light is available algae may be abundant in the biofilm, but in the darkness within the stream bed bacteria and fungi will grow using dissolved organic carbon from the water as their major food source (Campbell and Sterling 2006). They in turn provide food for a range of invertebrates which scape or brush material from solid surfaces – categorized as scrapers by Cummins (1973).

Macrophytes are generally not abundant in upland streams where the riparian vegetation is in good condition. The rapid current, and fluctuations in flow, and the shaded conditions make it difficult for larger plants to maintain their location and grow. However, where macrophytes do occur they are often rich and important habitats for other organisms (Boulton and Brock 1999).

Invertebrates comprise one of the most diverse groups of organisms living within streams. The insects, including groups such as mayflies, stoneflies and caddisflies, are the most diverse groups and also very abundant. Crustaceans, including freshwater shrimp and crayfish, are also important with some species of crayfish being consumed by people. Invertebrates are a key component of the food web, serving as food for many fish, platypus and water rats. They are also a sensitive group that is often used as an indicator of river health (Resh 2008).

Fish are important in streams for their ecological role, but also because of the popularity of fishing as a recreational activity in Victoria. The Victorian freshwater fish fauna is not notably diverse, but recent work has detected number of as yet undescribed species of native galaxiids. A number of native fish, including some of the undescribed galaxiid species, have very restricted distributions, and, as a consequence, are thought to be vulnerable to extinction. Several native freshwater fish species, including Barred Galaxias (*Galxias fuscus*), Australian Grayling (*Protroctes maraena*)and Trout Cod (*Maccullochella maquariensis*) are listed either nationally under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC) or under the Victorian Flora and Fauna Guarantee Act 1988 (FFG) or both.

Victorian streams support a number of other vertebrate animals including amphibians such as the Spotted Tree Frog (*Litoria spenceri*), also listed inder the EPBC and FFG acts, as well as aquatic mammals including the iconic platypus (*Ornithorhynchus anatinis*) and the water rat (*Hydromys chysogaster*). Both the latter two species feed primarily on aquatic invertebrates including freshwater crayfish and mussels.

What are the important ecological factors and processes influencing those biotic components?

Hynes (1970) was one of the first to ponder why so few of the organisms living in streams are sessile –that is living permanently attached to the stream bed. On rocky sea shores, which are also exposed to moving water from wave and tidal action there are many sessile organisms – such as corals, anemones, mussels and limpets whereas in streams most of the animals such as insects and crustaceans are very mobile. He concluded that the relative lack of substrate stability made it advantageous for organisms to be motile, so that they could relocate to suitable microhabitats when floods reorganized the stream bed, or when flows dropped during dry periods. Hynes initial ponderings led to four significant areas of research in stream ecology.

The first of these developed as concept of the unstable stream bed was extended from the 1980s to encompass an interpretation of floods acting as a disturbance which may be a factor in structuring stream invertebrate communities. This became a significant focus in stream ecology research internationally (e.g. see Clifford 1982, Ward and Stanford 1983, Reice 1985, Resh et al. 1988, Grimm and Fisher 1989, Flecker and Feifarek 1994, Death 1996, Townsend et al. 1997, Effenberger et al. 2006, 2008, Stanley et al. 2010) and within Australia (e.g. Doeg at al. 1989, Lake et al. 1989, Lake and Schreiber 1991, Downes et al. 1998, Lake 2000, Thomson 2002). Disturbance generally results in a reduction of the invertebrate fauna at the site of disturbance, presumably either through invertebrates moving out of the site or being washed out from the site.

Over a similar period there was an increasing international awareness that the habitat of stream beds was not uniform, that it is a patchy environment (e.g. Pringle et al. 1988, Townsend 1989, Palmer et al. 1995, Death 1996, Palmer and Poff 1997), and again Australian researchers were active in this research (e.g. Barmuta 1989, Doeg et a.l 1989, Downes et al. 1993, Lake 2000). The non-uniform nature of stream beds meant that the disturbance caused by floods was also not uniform throughout the habitat, and that ecological processes, and the abundance and diversity of the biota were also not uniformly distributed, but differed between habitat "patches". This has important implications when designing ecological experiments or monitoring programs or assessing environmental impacts, because the scale and location of the sampling units can have a substantial effect on the results obtained.

The third key area of research was work to attempt to quantify the rates of recolonization of patches of habitat following disturbance. This was most commonly done through artificial disturbance and then sampling the fauna of the disturbed patch at intervals following the disturbance. Notable international studies included the early work of Williams and Hynes (1976), and more recently by Mathaei and co-workers (Mathaei et al. 1996, Mathaei et al. 1997). Niemi et al (1990), and Yount and Niemi (1990) review much of the literature on these studies. There was also an active research program in Victoria by Lake and co-workers of recolonization rates by aquatic invertebrates (Lake and Doeg 1985, Doeg et al 1989a,b, Downes and Lake 1989, Lake and Schreiber 1991, Marchant et al. 1991).

Recolonization after disturbance generally occurs relatively rapidly, within days to weeks, through invertebrates being carried in the current (drifting) and invertebrates moving in from refuges (Sheldon 1984, Matthaei et al 1997). The time taken for recolonization has been found to be influenced by the mobility and density of invertebrates in adjacent undisturbed patches (e.g. Boulton et al. 1988, Marchant et al 1991) and the size of the disturbed patch (Resh et al 1988, Downes et al 1988, Doeg at al. 1989b). Repeated disturbance delays recovery (Clifford 1982, Death and Winterbourn 1995, Doeg at al. 1989a, Niemi et al 1990), and susceptibility to repeated disturbance, either because of the hydrology of the stream or the stability of the stream bed appears to influence the invertebrate assemblage at a site (Flecker and Feifarek 1994, Death 1996, Death and Winterbourne 1995, Downes et al. 1998).

The fourth area of intensive research attempted to identify what happened to invertebrates during disturbances such as floods. Recovery of the invertebrate fauna from even quite large natural floods was usually quite rapid, even though most invertebrates are not strong swimmers and could not possibly resist the current. Clearly there are refuges within the stream in which invertebrates can shelter out of the current during floods. A number of studies investigated the presence of potential refuge sites (e.g. Lancaster and Hildrew 1993a,b, Lancaster and Belyea 1997, Dole-Olivier et al 1997, Palmer et al. 1992, Robertson et al 1995, Sedell et al. 1990 Ward 1989). The hyporheos in the stream bed is one important refuge area (e.g. see Boulton et al. 2010), but backwaters and other sites within the stream will also serve as refuges. The hyporheos is the habitat within the stream bed, below the flow, and can extend a substantial distance vertically and laterally where the bed of the stream consists of loosely packed cobbles, pebbles and gravel.

While there have not been any specific Australian investigations of refugia, there is evidence of Australian stream insects utilizing the hyporheos to avoid excessive currents during spates in the

Wellington River (e.g. Campbell and Holt 1984). Sampling of the vertical distribution of invertebrates in the Thomson River found that most occurred in the upper 10cm of the stream bed, but up to 8% occurred at depths of 20-30cm within the streambed, with the proportion in the deeper levels increasing following floods (Marchant 1988). The importance of the hyporheos as both a refuge, and an important functional component of stream ecosystems has been a significant research field in recent years (Boulton et al. 2010).

The general conclusions from these four overlapping research themes has been that disturbance of the stream bed through pulse disturbances (*sensu* Lake 1990) during natural flooding or by physical processes such as raking and excavation, reduces the diversity and abundance of invertebrates on and in the stream bed as animals are washed out or move out of patches of stream bed. The biota subsequently recolonizes after the disturbance has ceased. Developing predictive models of the impact of disturbance and the trajectory to recovery has proven difficult because of the many influential factors involved (Stanley et al. 2010). For example the time of year of the disturbance (e.g. Marchant et al. 1991), the nature and natural stability of the stream bed at the site (Death and Winterbourn 1995, Effenberger 2006), the nature and size or intensity of the disturbance (Thomson 2002) the disturbance history of the site (Effenberger et al. 2006,2008), and the pre-existing biota.

The preceding discussion has focussed primarily on the relationship between the stream bed as a physical habitat and the stream biota, but water quality is also critical. The key relevant water quality parameter is the concentration of suspended particulate material (SPM) or suspended solids (SS). These may be measured directly, by filtering, drying and weighing, but also indirectly by measuring the turbidity, or cloudiness, of the water. Turbidity is a useful measure because it indicates how much light can pass through the water.

The biota of streams is strongly affected by the level of SPM. Plants and algae are affected because they depend on light for photosynthesis. Many fish and invertebrate species such many native galaxias and the large mayflies in the genus *Mirawara*, are visual predators , and unable to hunt effectively in turbid water. There are also many stream dwelling invertebrates that feed by filtering the water. They include many caddisfly larvae such as the Hydropsychidae, blackfly larvae (Simuliidae), some midge larvae (Chironomidae) and some mayflies (Coloburiscidae). Filter feeders are very sensitive to increases in inorganic SPM, because the particles fill the filtering apparatus reducing their feeding efficiency to the point where they either move to cleaner water or starve. Thus it is not surprising that, in experimental treatments where the concentration of inert SPM is increased in streams, there is a significant increase in the numbers of invertebrates that drift out of the treated section of stream (e.g. Doeg and Milledge 1991). Many of the effects of suspended sediment on the stream biota were reviewed by Hynes (1973) and Campbell and Doeg (1989). Stream sediments can also settle out, causing long term alteration to the stream bed (e.g. Beschta and Jackson 1979) and it was partly for this reason that it has been identified as a threatening process under the Victorian FFG Act. (http://www.dse.vic.gov.au/__data/assets/pdf_file/0003/103377/122_increase_in_sediment_input_2001.pdf). There is no general threshold below which increased levels of SPM will not affect the stream biota. The biota in streams with low levels of SPM will be more sensitive than that in streams which are normally more turbid.

How will prospecting influence those factors and processes?

There have been no specific studies examining the impact of prospecting on the ecology of streams, however there have been a number of studies evaluating the impact of eductor dredging (ENRC 1994)(including one conducted in dredged streams draining into Lake Eildon (Doeg 1985). That investigation did not find evidence that eductor dredging had seriously altered invertebrate communities in any of the streams sampled. However Hall (1988) noted that the Eildon study had not included sampling in summer or autumn, the seasons of intensive dredging, nor from slow water areas where most suspended sediment would settle out. In addition the study simply sampled rivers where dredging was known to have occurred, but it was not known whether the sites actually sampled had been subject to dredging. Nevertheless the dredging that occurred in the four rivers did not have a widespread substantial impact on aquatic invertebrate communities.

Studies of dredging in North America have detected impacts on both fish and invertebrates (e.g. Griffith and Andrews 1981, Harvey 1986). Where the area dredged was relatively small, and unimpacted areas which could act as sources of colonists were close, most studies have found a recovery of the invertebrate fauna within a few weeks to months. Dredging has been found to kill a substantial proportion of fish eggs and fish larvae entrained in the operation, but the impact on fish populations is not known.

An eductor dredge operation has a greater potential for impact on a stream than a prospector, because stream bed material can be excavated at a far greater rate, and usually with far less specificity. However the nature of the impacts on the instream habitat will be similar.

The excavating process will be in some respects similar to the disturbance created by a flood. The differences will be in the depth of the excavation, which, if it extends to the bedrock, or below about 20 cm below the stream bed surface, will disturb the hyporheos, a habitat which normally serves as a refuge when streams are disturbed by floods. In addition when the excavated material is returned to the stream bed it will not be packed as effectively as is the case naturally, leaving a weakness in the bed that may be less resistant to floods and therefore subject to increased disturbance in future.

Secondly the fine sediment generated from the prospecting, as with dredging, will settle out on the stream bed downstream. This may have a smothering effect on the local benthic invertebrate habitat, and the fine sediment will also block up the surface interstices restricting water flow into the stream bed, and thereby degrading the hyporheic habitat. With reduced water flow there will also be reduced dissolved oxygen available, and reduced food for those invertebrates which feed on transported particulate material.

The extent to which prospecting has a negative environmental impact at a given location will depend on a number of factors. Firstly the substrate present. Sandy bed material tends to have a low biomass and diversity of invertebrates, and so would be little affected by prospecting, similarly, in areas where there is extensive bedrock, disturbance to material collected in shallow grooves and pits in the rock would have little impact. However sites where the stream bed is armoured and there is an extensive hyporheic habitat will be far more sensitive to disturbance from excavation.

Secondly the time of year would be important. Many Victorian freshwater fish are known to have demersal eggs, including most of the galaxiid species. Demersal eggs are those that are simply released on to, and into, the stream bed. Stream bed disturbance during the breeding season could have significant consequences for these species, some of which are believed to have quite limited distributions. For example the Tapered Galaxiid is only known from the Aberfeldy River in the Alpine National Park. Specimens have recently been brought into a captive breeding program because of concern that water quality changes and sedimentation as a consequence of the recent bushfires could render the species extinct. In addition floods and high flow periods will tend to sort and repack the stream bed materials. So a bed disturbance from prospecting shortly before a high flow will be of less consequence to the physical bed structure than one which occurs prior to an extended low flow period.

Thirdly the proportion of the stream bed disturbed by prospecting would be important. Clearly if only a very small area of stream bed were to be excavated then the ecological impacts would be small. However if a large proportion of the stream bed is excavated and processed, either by a single prospector working over a long time period, or by multiple prospectors over a shorter time, then the risk of significant impact also increases.

Fourthly the frequency of prospecting is an important consideration. With apparent recovery times following disturbance of weeks or months, if prospecting occurred at a site only once each year the impact is likely to be slight, however in sites prospected say weekly, impacts are likely to become quite apparent.

Finally the location itself is important. Victoria has identified a number of freshwater invertebrates amphibians and fish which are considered to be of conservation significance, in most cases because they have very limited distributions ,such as some galaxiid fishes and alpine stoneflies, or because their populations have substantially declined and are now known or believed to be very small, such as the Spotted Tree Frog, Trout Cod and Grayling. Many of these species are listed in the Victorian Advisory list of Threatened Species (http://www.dse.vic.gov.au/plants-and-animals/native-plants-and-animals/threatened-species-and-communities/threatened-species-advisory-lists). A number of such species are known to occur in streams in auriferous areas within several of these parks. These include the Tapered and the Dargo galaxias, two as yet undescribed fish species which are known from streams in the Alpine National Park (Raadik and Nicol 2012, Tarmo Raadik personal communication), as is the Alpine Stone Fly (*Thaumatoperla alpina*), the Alpine Spiny Crayfish (*Euastacus crassus*) and the Spotted Tree Frog (*Litoria spenceri*) (http://www.dse.vic.gov.au/__data/assets/pdf_file/0007/103201/112_spotted_tree_frog_2000.pdf). Several other alpine aquatic species characteristic of small streams are listed as data deficient, including two further stonefly species: *Thaumatoperla robusta*, and *T. timmsi*. The *Thaumatoperla* species utilize the hyporheos extensively and are therefore susceptible to any disturbance which could interfere with that habitat. Obviously conducting prospecting at sites where such species occur creates a much greater environmental risk than prospecting at sites where the fauna comprises widespread species.

Conclusions

Prospecting activities in streams in Victorian National Parks have the potential to create appreciable ecological risks. The risks will vary depending on the specific location, because different locations have different stream characteristics and some locations may have species present which have particular conservation significance. The risks will also depend on the intensity of the prospecting activity at a particular site – the number of prospectors, the extent of the prospecting, and the frequency of prospecting, with higher intensity prospecting posing greater ecological risks.

A series of risk analyses conducted on a park by park basis would be advisable to ensure that locality-specific factors were adequately considered before deciding whether or not prospecting constituted an acceptable risk in any particular river system or park.

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Appendix 1.

Maps of the selected parks indicating the auriferous areas which are of interest to prospectors.