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Zinc-Lead Mines in Ireland: Approaches to Groundwater Control and Protection

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ABSTRACT

In the past 25 years, three major underground zinc-lead mines have been developed in Carboniferous Limestones in Ireland: at Navan in County Meath (1976), Galmoy in County Kilkenny (1995) and Lisheen, County Tipperary (1997). All three mines are in agricultural areas with no previous history of mining activity, and great importance was attached to minimising their environmental impact. In the cases of Galmoy and Lisheen, the host rocks were considered to be important aquifers, and the prediction and control of mine dewatering were substantial issues at the planning stage. In all three cases, the potential impact of seepage from a tailings dam was an important issue, as was the proposed closure plan. Galmoy and Lisheen mines are still in the early stages of their development, and the effects of mine dewatering upon the aquifer are only beginning to be seen. Tara Mine at Navan is a mature mine which recently applied for permission to extend its tailings dam vertically by a further eight metres, providing an opportunity to review the environmental impact of the existing dam.

The developers of the three mines have employed somewhat different approaches to the mine planning and construction, in relation to mine dewatering, tailings management and closure plans. This paper discusses the varied approaches and the experience to date in monitoring the environmental impacts of the three mines.

INTRODUCTION

Ireland is Europe's leading producer of zinc concentrate and a significant producer of lead concentrate. Three major underground zinc-lead mines have been developed in Carboniferous Limestones in Ireland in recent years: at Navan in County Meath (1976), Galmoy in County Kilkenny (1995) and Lisheen, County Tipperary (1997) (locations in Figure 1). Although Ireland has a history of mining going back several hundred years, these mines are in agricultural regions with no previous experience of mining, where special care was needed with regard to environmental protection. Moreover, the mines at Galmoy and Lisheen involved mining in limestone aquifers, which posed particular problems regarding dewatering and pollution control.

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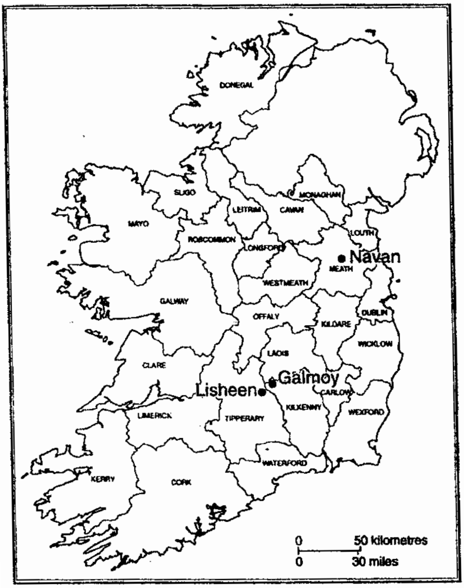

Figure 1: Locations of Recent Large Zinc-Lead Mines in Ireland

LOCATION, GEOLOGY AND MINING METHODS

Tara Mine, Navan, County Meath

The Navan orebody was discovered in 1970 on farmland just outside the town of Navan, County Meath, about 40km north of Dublin. The area is flat lying and the main feature in the area is the River Blackwater which flows across the deposit.

The orebody occurs near the local base of the Carboniferous Limestone sequence in 200m of partially dolomitised bioclastic limestones and calcareous sandstones which rest unconformably on Lower Palaeozoic rocks (Ashton and others, 1986). The ore-bearing horizons pass upwards into unbedded Waulsortian micrites. The succession is interrupted by an erosion surface overlain by a boulder conglomerate succeeded by alternating dark shales and calcarenites. The area is covered by Quaternary sands, gravels and tills.

The ore is stratiform; it subcrops to the northeast and dips generally southwest at about 20°, reaching depths approaching 1000m. A series of northeast trending faults disrupt the succession. These both pre- and post-date the erosion surface which truncates the main mineralised horizons.

The orebody north of the Blackwater river became unavailable to the discoverers (Tara Exploration and Development Ltd.) because of mineral ownership issues. When development started, the southern part contained resources of 70 Mt grading 10.1% zinc and 2.6% lead.

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The development consists of a 2.2 Mtpa (later increased to 2.6 Mtpa) underground mine with backfilling. Access is by a 300m vertical shaft and a decline. Mine water is collected in sumps and pumped to the tailings pond. Surface facilities include conventional milling and flotation. Tailings not used for backfill are disposed of in a Management Facility (TMF) 5km north of the mine (Frame 1974, Libby and others 1985). This 160ha site is relatively flat and required a ring dam 8m high, constructed mainly from on-site glacial till with a central drainage chimney connected to an interceptor ditch which was intended to collect any seepage.

Mining commenced in 1977. By the mid-1990s it became clear that Tara had insufficient tailings storage capacity on surface for the remaining reserves and resources which still exceeded 20 Mt, and additional capacity would be required if the mine were to continue beyond 2000. Tara (which had by then been taken over by Outokumpu Oy of Finland) after considering various alternatives, proposed to increase capacity on the existing site by constructing a new dam 8m high built on the existing tailings.

Galmoy Mine, County Kilkenny

The Galmoy deposit was discovered in 1986 by Conroy Petroleum and Natural Resources, then a small Irish company, 110km southwest of Dublin, in a mainly rural area with numerous single dwellings and farms, predominantly livestock. The nearest village is Rathdowney, 6 km away. Several small streams cross the area which is one of undulating topography (130-200m OD). There are two wetland areas of some conservation importance in the vicinity.

The geology consists of gently dipping argillaceous bioclastic limestones (120m thick), overlain by massive Waulsortian mudbanks (160 to 200m thick) which are intensely dolomitised in this area (Doyle and others, 1992). The two stratiform orebodies (designated 'CW' and 'G') totalling 6.12 Mt, grading 11.5% zinc and 1.11% lead and with locally high pyrite, lie at the base of the Waulsortian, 50 to 110m below surface (average 70m) and about 1.5km apart. The main structural feature is an easterly trending normal fault dipping to the north which bounds the south of the 'G' orebody. There are numerous northwest trending joints and minor faults, often with intense fracturing. Palaeokarst development, (probably Tertiary in age) consists of mainly sediment filled cavities but no cave systems were identified. There is no evidence of active karst. The lower lying parts of the area are blanketed by glacial tills and occasional interbedded sands and gravels, generally about 5m thick.

The development, with a capacity of 650,000 tpa, consists of an underground mine with backfilling; underground access and ore transport along crosscuts to a decline midway between the orebodies in the Waulsortian dolomites; conventional grinding and flotation on surface; and tailings disposal on a site 300m from the nearest known ore. The TMF, in a low valley, has an engineered ring dam built from local glacial materials with chimney and finger drains of sand. The base of the facility is sealed with a double HDPE liner. Development began in 1995, and production in 1997.

Lisheen Mine, County Tipperary

The Lisheen deposit was discovered in 1990 under a Joint Venture between the Chevron Minerals Corporation of America and Ivernia West plc, which was then a small Irish company. Chevron later sold its stake to Minorco and there is now a 50/50 partnership between Minorco and Ivernia, with Minorco as managers and operators of the project. The deposit is located 8km

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southwest of the Galmoy deposit in a generally similar rural area 12km northeast of Thurles (the nearest town) . Notable differences on surface are that:

a) it is on the edge of the Derryville Raised Bog which has been exploited for many years for milled peat.

b) many properties close to the mine are supplied with water by a co-operative, the Moyne Group Water Scheme, rather than having their own wells. The main source well for this scheme was located close to the deposit. A County Council regional scheme supplies the area to the north.

The geological setting is quite similar to Galmoy. Two flat-lying stratiform orebodies (the Main and Derryville zones) with total reserves of 18.9 Mt at 12.5% Zn and 2.5% Pb and about 17% Fe, occur at the base of the dolomitised Waulsortian at an average of 190m below surface. They are bounded to the south by two *en echelon* normal faults, downthrown 200m to the north which bring the underlying argillaceous bioclastic limestones and oolites into contact with the ore (Hitzman and others, 1992). There is a north-south joint and fault system. Paleokarst occurs in the area, expressed mainly as sediment-filled fissures. The most significant feature is an infilled palaeodoline, at least Tertiary in age, over 40m in diameter and up to 80m deep. There is no sign of active karstification at present.

The development consists of a 1.5 Mtpa underground mine with backfilling; conventional grinding and flotation on surface; and tailings disposal mainly on the worked peat bog immediately east of the plant site, 1km from the nearest ore and south of the fault complex. Primary access is by a decline constructed to the south of the faults where the Argillaceous Bioclastic Limestone provides much better ground conditions and lower mass permeabilities than the Waulsortian. Development began in 1997. The TMF is designed as a water retaining structure comprising a perimeter embankment with internal drainage. The peat will be stripped from the dam footprint but left in place as an attenuating layer under the tailings and covered by a LDPE geomembrane.

THE PERMITTING PROCESS SINCE 1970

Mines require a State Mining Facility under the terms of the Minerals Development Acts 1940 to 1995. These relate to the rights of working minerals and are concerned to only a very limited degree with any environmental issues, which are regulated through Planning and Discharge licensing procedures which have developed incrementally through the last thirty years.

The basic control of development in the early 1970s, when Tara was seeking its first permissions, was through the Local Government (Planning and Development) Act 1963 and its associated Regulations. This required that Planning Permission be obtained from the local authority (Meath County Council) for any new development. However, the 1967 Regulations exempted underground mining from this control so that Tara required permission only for its surface works. In the 1970s there was no active "environmental" lobby and only minor local opposition: mining and industrial development of all kinds was widely welcomed as an opportunity for job creation and greater economic development. The planning process was muted and Planning Permission was issued in 1975 for the plant and TMF. No separate licences were needed for air or water discharges. An Environmental Impact Statement was not required.

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Effluent Discharge Licenses were required by the Local Government (Water Pollution Acts) 1977 and 1990.

Formal Environmental Impact Assessment was introduced into Ireland by the European Communities (Environmental Impact Assessment) Regulations 1989, and mining was included. Other regulations introduced in 1990 withdrew the exemption from the planning process previously enjoyed by underground mining.

Thus, by the time that permission was being sought to develop the **Galmoy** mine, in addition to the requirement for Planning Permission for all parts of the operation, to be accompanied by an Environmental Impact Statement, a Licence was required for discharges to water, whether surface or underground. Kilkenny County Council was the competent authority for both processes, but its decision could be appealed by any party (including members of the public) to An Bord Pleanála, an independent agency whose decision is final (except on points of law). Conroy began its Environmental Impact Study in 1988 and submitted its planning and licence applications in December 1990. Subsequently Conroy took over another Irish company and was renamed Arcon International Resources plc. Kilkenny County Council raised numerous queries on the initial applications, and the new management decided to withdraw them in March 1992. New applications were made in December of that year. Permissions were granted in 1993 against vociferous local opposition and were appealed to An Bord Pleanála, which granted final permission in 1994 following a public hearing.

The Environmental Impact Study for **Lisheen** began in 1991. A new system of pollution control was introduced by the Environmental Protection Agency (EPA) Act, 1992, which established the EPA as a new agency dedicated to environmental control and introduced the Integrated Pollution Control Licence (IPCL) for certain industries, including mining. The Act was brought into force for new mining projects in 1994 and the Lisheen project was one of the first major projects of any type to be considered by the new agency. The IPCL replaced the Water Discharge and Air Pollution Licences and transferred responsibility for considering noise, vibration, and waste management from Planning Authorities. The Licence is concerned only with emissions, so water pollution is included but all issues relating to loss of water supplies remain a planning function.

Completion of the EIS was somewhat extended by the sale of Chevron's holding but Planning and IPCL applications were submitted early in 1996, following an extensive and mutually beneficial process of pre-consultation with the regulatory authorities and with local interests. Planning Permission was granted by the County Council in August 1996. The developers had been very pro-active with the local residents and there was little significant opposition. There were, however, some appeals to An Bord Pleanála and final permission was not granted until May 1997. An IPCL was issued by the EPA in the following month and construction started in September.

Whilst **Tara's** application for an extension to its TMF followed the introduction of the IPCL, it does not yet apply to existing mines so that only Planning Permission was needed. An application was submitted in 1996 and Meath County Council issued a draft Planning Permission in 1997 including a rehabilitation surety of IR£2.5m. This Permission has been appealed to An Bord Pleanála for final adjudication.

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GROUNDWATER ISSUES

Tara Mine

Whilst no EIS was required for the original development, Tara carried out a voluntary study, following the methods then emerging in North America (Dallas 1977, Frame 1974). Groundwater was identified as an issue only insofar as it might affect domestic wells which still supplied a number of individual farms and houses and Tara carried out well surveys before applying for Planning Permission. The Planning Permissions contained a general condition requiring 6-monthly monitoring of wells around the tailings dam. However, the Minerals Development Acts impose a strict liability on miners to pay compensation for any loss of or damage to water supplies and Tara implemented a policy of replacing water supplies by connection to the County Council's water supply system. No claims have arisen.

In practice Tara's approach has been successful in relation to the underground mine. The shaly limestones which cap the ore-bearing horizons are relatively impermeable; 6000m^3/day is pumped from the sumps (Dodds et al. 1994). This inflow is mainly along a fault and has resulted in a limited cone of depression elongated to the southwest. The water chemistry is closely monitored to ensure that is no connection is being opened, by ground movements from mining, to the River Blackwater.

There were two main groundwater issues connected with the recent proposal to increase the capacity of the TMF:

⇒ It emerged during the Environmental Impact Study that the peripheral interceptor ditch had proved locally ineffective and a sulphate enriched pollution plume had developed in the surficial deposits and this attracted public attention. Seepage from the dam and the extent of sulphate contamination had been greater than should have been allowed; operation of the interceptor trench had been less than ideal; and Tara's monitoring had been inadequate. However, the monitoring of sulphate levels indicated that no well had been affected. The issue was adequately addressed in the EIS, and modelling indicated that the modification of the interceptor channel should result in an improvement in groundwater quality from its present condition. The application contained proposals to deepen the interceptor trench and to ensure that it remains effective even when the site is eventually closed.

⇒ There is some evidence of palaeokarst, but after examination of the issue, it was concluded that there is no significant karstic permeability in the area. This was supported by the relatively high piezometric levels in the bedrock (normally higher than in the superficial deposits) and the pattern of sulphate contamination, which appears to have no close relationship with bedrock features such as a fault across the area.

Galmoy Mine

It was clear from an early stage that this development could have significant impacts on groundwater. A substantial part of the EIS and the subsequent questioning by the County Council was devoted to these. Hydrogeological work included a comprehensive well survey; 5 years' monitoring of over 50 wells; and extended pumping tests on 3 test wells (with multiple observation wells). Numerical modelling was carried out for the CW ore body only since the G ore would not be mined for about five years. A two layer MODFLOW model was used; the upper layer

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representing overburden and the first 10m of (weathered) bedrock and accounting for about 85% of groundwater throughput and a lower layer with varied (generally lower) transmissivity to represent the mix of fracture zones and unfractured rock. The G fault was modelled as a barrier. The model was calibrated against the baseline data.

The following were the main groundwater issues:

- The dewatering of the mine was predicted to produce a substantial cone of depression which would affect many domestic wells in addition to a spring adjacent to the mine site which formed one of the main sources of supply for Rathdowney. There was also concern that dewatering could affect agricultural productivity by reducing soil moisture.
- Some local streams, used inter alia for watering cattle, would be dried up at least seasonally.
- The local wetlands might be affected.
- 10,800m^3/day might have to be pumped to keep the mine workings dry. If pumped from the mine sumps, this could cause problems with meeting dilution requirements, given the size of the River Goul into which it was to be discharged.
- There might be potential for reactivating palaeokarst features, one of the more significant of which was known to lie under the proposed TMF. Concerns were expressed that this could de-stabilise the dam wall.
- Some of the ore could be potentially acid generating, and there were minor concerns about the potential for Acid Rock Drainage from either the TMF or underground to pollute groundwater. (The main requirement was to ensure that the surface layers of tailings would be inert and could be revegetated.)

The developers offered considerable mitigation, including

- The provision of a new water scheme extending over the projected cone of depression (extending 2 to 2.5km from the CW orebody), with water to be supplied free of charge. A detailed study of soil moisture controls showed that this did not depend on the water table level.
- Augmentation of streams to make up any water losses.
- Provision of make-up water, if necessary, to the more significant of the wetlands.
- A perimeter well field to minimise the amount of contaminated mine water and to provide additional dilution for mine and mill effluent.
- A lined and engineered TMF, with extensive pre-testing of the site. It was accepted that it is virtually impossible to ascertain the location or size of any karst cavities by any combination of drilling or geophysical exploration, and that collapse was most likely to happen (if at all) when the water table had been drawn down below the glacial deposits and the site then flooded. It was therefore proposed that, following a substantial period of dewatering, the TMF site would be subjected to a full-scale flooding test. If no collapse occurred during this test, the TMF design and construction could proceed without modification. If any collapse occurred, the collapsed areas would be treated accordingly.

These commitments were reinforced by 14 Conditions (out of 68) in the Planning Permission, and by 13 (out of 84) in the water Discharge Licence. Other conditions contained general points of relevance, covering such issues as detailed design of the perimeter wells, the water replacement scheme, review of the groundwater modelling, a requirement for continued pumping and treatment of water from the mine after re-watering until quality is satisfactory, sealing of

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boreholes, and monitoring groundwater quality and the development of the cone of depression. An IR£4.5m surety was required to cover all aspects of closure.

Lisheen Mine

Not surprisingly, given the similarity and proximity of the Galmoy and Lisheen projects, the main groundwater issues were similar, though with differences of emphasis:

- Replacement of water supplies: the predicted ellipsoidal cone of depression extends 3 to 7km from the mine site, with an area of about 70 km^2 within the 1m drawdown contour.
- Potential volumes of polluted mine water.
- Groundwater-induced karst-related subsidence.
- Stability of the TMF.
- Contamination of ground (and surface waters) by leachates from the TMF or from underground after closure.

The base line studies and modelling were also generally similar including well surveys, pump tests, a generally similar conceptual model, and use of MODFLOW. However, the Lisheen model used four layers - (1) soil & overburden; (2) & (3) upper and lower dolomite/limestone aquifer; and (4) poorly permeable argillaceous limestone. An anisotropy ratio of 3:1 (N-S : E-W) was used to represent the higher permeability in a N-S direction (due to fracturing) in layers 2, 3 and 4.

Solutions proposed included:

- Provision of compensatory water supplies for the Moyne Group Water Scheme and the County Council to ensure that their water supply systems remained effective and were extended if necessary; individual wells on the periphery would be deepened or replaced.
- Stream augmentation.
- Perimeter dewatering at a predicted rate of 27,000m^3/day.
- Monitoring and reinstatement of any subsidence.
- Selection of a TMF site in an area with low paleokarst potential.
- Provision of satisfactory evidence that the TMF site was stable.
- Lining of the TMF to augment the natural barrier provided by the underlying peat, and a wetland endpoint to prevent ARD.
- Partial rewatering of the mine after closure and controlled pumping and treatment until groundwater quality recovers.

The developers and their advisers (several of whom had been involved in consideration of the Galmoy application) took account of the experience at Galmoy and made considerable efforts to satisfy the authorities and local interests, especially the Moyne Group Water Scheme, in advance. Thus, whilst there were numerous questions and requests for information on points of detail and for data to substantiate the conclusions, there was relatively little controversy.

Groundwater issues were nonetheless significant, and the Planning Permission and IPCL contain Conditions to reinforce the developer's commitments, as in relation to water supply replacement and construction of dewatering wells. An IR£9.5m surety for closure was required.

Since development is still at a relatively early stage, it not yet possible to assess the accuracy of the predictive work on dewatering, in particular the extent of the cone of depression.

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DISCUSSION

Dewatering

Tara's approach, in the 1970s, was a simple one and did not involve numerical modelling. It was assumed that the overlying rocks were a poor aquifer and formed an effective barrier isolating the ore horizons, except possibly along major faults, that the mine could safely use the development phase to acquire information, and that monitoring of wells would give adequate information on the spread of the cone of depression to allow timely replacement of water supplies.

Both Galmoy and Lisheen took a similar approach to mine dewatering: the rock above the ore zones was to be dewatered by a series of perimeter wells, down to a level some 20-40m above the ore. The pre-dewatering will not go deeper, to avoid pumping water contaminated by ore minerals. Dewatering of the ore zones is by in-mine drainage and pumping. It is thus intended to separate the 'clean' water from the perimeter wells, which can be discharged (after conditioning) directly to a river or supplied for drinking, etc., from the 'dirty' water from the mine sumps, which can be used in mine processing but requires treatment before disposal to any watercourse.

Because of fears relating to the potential for re-activation of infilled palaeokarst voids, the planning conditions contain strict specifications for the construction of the dewatering wells, to minimise and monitor any pumping of sand, which might ultimately lead to wholesale mobilisation of cavity fillings and thence to collapse of karst voids.

In practice, as experience at Galmoy has shown, it can be difficult to locate good sites for dewatering wells in an erratic fracture-flow aquifer, and the design concept was only partially successful. Consequently the ratio of 'clean' to 'dirty' water is lower than predicted even though they are separated in-mine, but as the overall water intake is also lower than predicted, the water treatment capacity has not been exceeded. The cone of depression is also much smaller than predicted. It remains to be seen whether the same scenario develops at Lisheen.

Modelling

The modelling exercises had two primary objectives:

- To predict the volumes of water which must be pumped in order to operate the mine.
- To predict the extent of the Cone of Depression and therefore the effects on existing water users.

The conceptual models used at Galmoy and Lisheen were based on extensive geological and hydrogeological investigations by Geological Survey staff over a number of years (e.g. Daly, 1994) and the additional work during the site investigations. At Tara the conceptual model was simpler in that the bedrock was essentially treated as an aquitard and the hydrogeology was more influenced by the permeability of the unconsolidated Quaternary deposits.

The basic aquifer modelling in all three cases used MODFLOW, it being an industry-standard, well-established package. However, the three models differed in several respects. This meant, in particular, that it was not easy to match up the Galmoy and Lisheen models even though they covered immediately adjacent areas.

An obvious possible concern about the use of MODFLOW is its applicability to fracture-flow aquifers. However, it was generally accepted that (a) the scale of the areas in relation to the scale of the fracture networks made its use acceptable, and (b) the use of less well-proven fracture-flow models would not be appropriate.

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The aquifer parameters were derived from a substantial body of field investigation and broadly conformed with the Geological Survey's knowledge of the hydrogeology, although the values for specific yield were lower than expected.

The models were calibrated against a substantial body of data (stream flows, rainfall, groundwater level contours and fluctuations, etc.) and underwent adequate sensitivity analysis. One interesting point to emerge from the modelling was that calibration required recharge estimates significantly lower than have been assumed hitherto. The Galmoy and Lisheen developments can be seen as very long-term pumping tests which will reveal a great deal about the aquifer properties of the host limestones and their effective recharge. The modelling suggests that drawdowns will almost stabilise after about five years. The actual results are awaited with interest.

The presentation of the predicted Cone of Depression was a significant element in the Environmental Impact Statements. Since the extent of the cone of depression is normally shown by a selected drawdown contour, it is important to strike a balance between over-precision (e.g. 0.1m), which is unrealistic in view of the limitations of the model, and over-simplification (e.g. 2m), which neglects significant effects on shallow dug wells. The degree of uncertainty in the predictions is greatest near the margin of the cone of depression, and any developer is understandably reluctant to open itself to unwarranted claims - e.g. for abandoned or disused wells, or wells at the very margin of the affected area. However, some degree of over-compensation may be inevitable.

Given the level of uncertainty in model predictions, it is essential that predictions should not be presented as a single outcome but as a range within which the likely outcome should fall. The range need not include a 'worst possible' case but does need to be conservative since the water replacement schemes and dewatering systems must be designed around it.

The models for Galmoy and Lisheen were both revised as a result of comments concerning the modelling. In Lisheen's case, the model was revised to produce a better fit with the earlier Galmoy model, and its northern boundary was extended 10 km to the north, to allow a better definition of the cone of depression (previously limited by the model boundary).

Prediction of loss or diminution of water supplies

The drying-up of existing wells in the cone of depression is the most immediate effect of major mine dewatering but it is also the easiest to remedy, normally by providing an alternative supply. In each case a comprehensive well survey in the affected area recorded the details of each source and estimated existing usage. Ireland has a strong tradition of 'Group Water Schemes', set up and managed on a co-operative basis but subsidised by Government. In the above cases, owners of affected wells could choose between connection to a Group Scheme or having an individual supply. Protection of the interests of existing water users is a primary concern of Government and critically important locally. A developer must be as "up front" as possible on this issue.

Karst

The orebodies at all three mines are hosted by carbonate rocks, and most carbonate formations in Ireland exhibit some features due to enhanced solution, which can be referred to as 'karstification'. The degree and extent of karstification are very variable, being generally greatest in the purer limestones and least in the more argillaceous rocks, but it is also affected by the degree of fracturing and the geomorphological history. Since the term 'karst' is associated, in its classic form, with large caverns, underground rivers, and spectacular collapse features, the term can be used by

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opponents of a development to conjure up a prospect of disastrous consequences of mining. In the event, karst became a seriously contentious issue only at Galmoy, and its resolution undoubtedly helped to reduce the contentiousness of the later Lisheen and Tara applications.

Methods used to investigate the degree of karstification and to identify karst-related cavities were fairly conventional: the carbonate formations were assessed for their general susceptibility to karstification, and critical areas (especially beneath TMFs) were investigated by exploratory drilling, and geophysical methods - VLF and GPR - the latter, in particular, proving unsuccessful.

It is probably inevitable that there will be some re-activation of karst voids in the mined area, and the impact of this, and mitigation measures, have to be presented (bearing in mind that monitoring is *not* mitigation). Meanwhile there has been a renewed interest in quantifying the extent of karstification in Irish limestones away from our classical karst regions.

Tailings Management Facilities

A notable feature of all three developments is that the dams are engineered as water retaining structures, constructed of compacted fill with internal drainage and not from tailings. These standards are to ensure that the risk of dam failure, or development of serious leaks, should be negligible. Any future TMFs in Ireland can be expected to have to meet similar standards of integrity since the EPA has indicated that it regards mine wastes as no different in principle from any other non-hazardous industrial wastes and will require the appropriate land-fill design.

The three developers have taken different approaches to the final end-points for their tailings dams though with the same objective of ensuring physical and chemical stability: Tara and Arcon plan a conventional dry end-point, with the tailings re-vegetated to ensure surface stability. Lisheen, where the tailings are potentially acid generating, plans a wetland in which oxidation is prevented by perpetual saturation.

It is essential for the successful operation of the proposed Lisheen wetland that it never dries out, i.e. that a sufficient depth of water is maintained at all times over the surface of the deposit. It is assumed that this will be achieved by purely natural means, i.e. by excess rainfall.

Post-closure contamination

In all three mines, it is vital to prevent pollution of the groundwater after mine closure. Predictive modelling of water table rebound, solute transport (e.g. with ASM), and particle tracking, indicate that this can be achieved, but it will be important to up-date the modelling as more data become available during mining. Conditions imposed by the regulatory authorities aim to ensure that mine operation, monitoring and model review will ensure the optimum post-closure outcome. Each developer has had to post a substantial surety to guarantee that funds will be available for planned closure and to ensure that adequate measures can be taken in the event of either premature closure or post-closure problems requiring remediation.

Regulatory environment

As mentioned above, the regulatory and administrative environment governing mining have undergone several changes over the past 25 years. Currently, a developer must submit three applications: to the planning authority for planning permission, to the EPA for an Integrated Pollution Control Licence, and to the Department of the Marine and Natural Resources for a State Mining Facility (Lease or Licence, depending on the mineral ownership status). In theory, this may

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appear cumbersome. In practice, different permits cover different aspects of the developments, the three authorities co-ordinate closely, and the Lisheen case has shown that, with appropriate pre-consultation and simultaneous applications, even a major development can proceed fairly smoothly, provided that the developer takes its environmental responsibilities seriously. Maintenance of a high quality environment is a high priority in Ireland. Mining is regarded with some wariness by the general public, not least because of various well-publicised incidents abroad. These developments show that high standards can be achieved by the mining industry, albeit at a price since the measures discussed in this paper cost over $10 million for each operation.

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