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Review

Realizing Beneficial End Uses from Abandoned Pit Lakes

Cherie D. McCullough [1,*], Martin Schultze [2] and Jerry Vandenberg [2]

[1] Mine Lakes Consulting; cmccullough@minelakes.com
[2] UFZ-Helmhotz-Centre for Environmental Research; martin.schultze@ufz.de
[3] Vandenberg Water Science; jerry@vws.ltd

* Correspondence: cmccullough@minelakes.com

Abstract: Pit lakes can represent significant liabilities at mine closure. However, pit lakes also present opportunities to provide significant regional benefit and address residual closure risks of both their own and overall project closure, and even offset the environmental costs of mining by creating new end uses. Unfortunately, many pit lakes have continued to be abandoned without repurposing for an end use.

We reviewed published pit lake repurposing case studies of abandoned mine pit lakes. We found beneficial end use type and outcome varied dependent upon climate and commodity; but equally important social and political dynamics that manifest as mining company commitments or regulatory requirements. Many end uses have been realized: passive and active recreation, nature conservation, fishery and aquaculture, drinking and industrial water storage, greenhouse carbon fixation, flood protection and waterway remediation, disposal of mine and other waste, mine water treatment and containment, and education and research.

Common attributes and reasons that led to successful repurposing of abandoned pit lakes as beneficial end uses are discussed. Recommendations are given for all stages of mine closure planning to prevent pit lake abandonment and to achieve successful pit lake closure with beneficial end uses.

Keywords: mine lake, pit lake, closure, planning, repurposing, end use, water quality

1. Introduction

Mine pit lakes are created, intentionally or otherwise, when open cut mine voids fill with water after mining and dewatering cease [1]. When voids extend below regional groundwater levels, groundwater inflows may be the dominant contribution and controls to final lake volume and depth respectively [2, 3]. Where surface water flows are significant into and/or out of the pit lake then this water source may be more important in controlling pit lake hydrology and quality [4, 5].

There is growing recognition that pit lakes can represent significant liabilities at mine closure; particularly to the environment [6]. With over ½ century of open cut mining demonstrated in most countries, pit lake legacies have been shown to present long-term and significant health, safety and environmental risks that are difficult to resolve [7]. These risks are in particular poor water quality (elevated metal concentrations and/or acidification due to mobilization of metals as contaminants of potential concern (COPC) and oxidation of sulfide minerals, particularly pyrite) [6, 8, 9], unstable sidewalls and, thus, landslides [10, 11], and steep sidewalls accompanied by the risk of fall and drowning [12, 13]. These risks can typically be mitigated by closure planning and associated technical measures during mining and closure or following relinquishment [7, 10, 11, 14].

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However, pit lakes are one of the few closure landforms that concurrently present opportunities to address residual closure risks of both their own and overall project closure [15, 16]. The following end uses have been realized: passive and active recreation, nature conservation, fishery and aquaculture, drinking and industrial water storage, greenhouse carbon fixation, flood protection and waterway remediation, disposal of mine and other waste, mine water treatment and containment, and education and research [13].

Determining end-use values is a first stage in assessing opportunities posed by the pit lake and the extent of works and ongoing management that may be required to achieve this opportunity [17]. A clear definition of intended end use values during closure planning (even at approvals stages) can direct operational activities and closure works toward reliably achieving these values.

Typically values fall within three types (Figure 1):

1. wildlife;
2. recreation; and,
3. primary production.

This approach allows flexibility in applying closure objectives and criteria to be based on the geochemical and social/environmental baseline conditions relevant to a particular mine site.

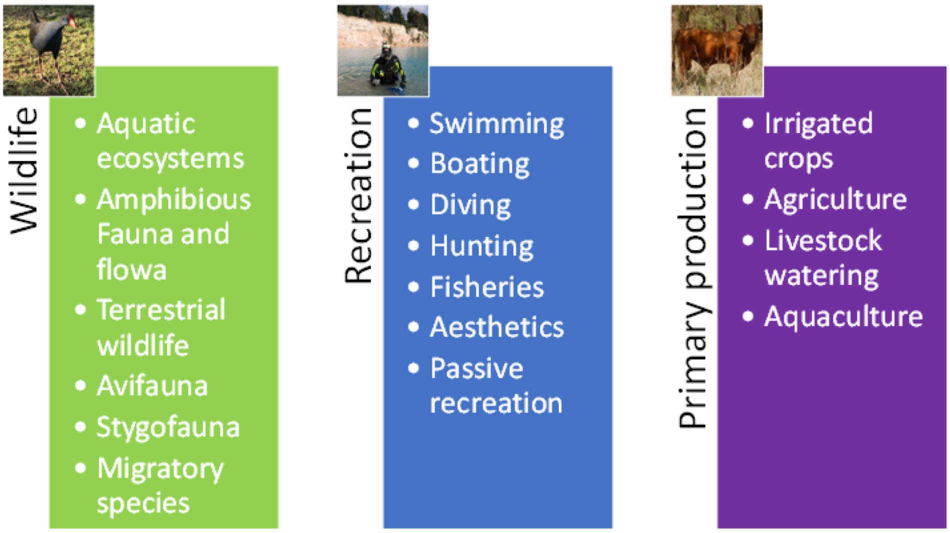

Figure 1. Key end use value definitions for pit lakes.

In this paper we provide examples of existing pit lake end uses and some collective insights from our work across three continents, and internationally, as to what end uses have been successful; and why.

2. Approach

Using the Mine Lakes Consulting pit lake database we reviewed 247 published articles, book chapters and unpublished industry studies combined with our own collective and international experiences for a range of abandoned pit lakes, their key attributes and the success of their outcomes.

As previous studies have found [15, 18], most pit lakes were located in Australasia, Europe and North America. Although, the higher number of pit lakes in these continents is to some extent an artefact of the authors' locations and native languages in addition to where most publishing activity has occurred, we focused on lakes from these continents where there was a greater knowledge base (Table 1). Within this dataset, most pit lake lakes were in Canada (45), USA (29), Czech Republic (26), and then Australia and Germany (24 lakes each).

3. Realized end uses

Our review identified a number of end uses that have been realized in abandoned pit lakes. Key end uses were defined as follows:

- Wildlife: Providing significant wildlife habitat for aquatic and/or amphibious ecology.
- Fishery: Used as either an incidental, planned or stocked fishery; or for the purposes of aquaculture. Fin fish, crustacea or otherwise.
- Recreation: Active recreation such as swimming, boating, water skiing and SCUBA diving. Also including passive recreation of water-oriented amenity such as picnic areas and walking/biking trails around the lake.
- Source and storage of water: Providing a water source for either potable, irrigation (agriculture or horticulture) or for industrial purposes and storage space for regional water management including flood protection.
- Waste storage and treatment: Used as a waste storage receptacle. Either mine wastes or unrelated wastes such as from nearby industries.

Table 1. International pit lakes with defined pit lake end uses (n>1).

Country	Fishery	Wildlife	Recreation	Source	Waste	Total
Australia	6	7	8	2	2	25
Canada	22	6	2		5	35
Czech Republic	7	11	18	11	3	50
Germany	2	2	10	0	2	16
New Zealand	0	2	1	0	0	3
Poland	5	13	0	0	1	19
Spain	0	0	1	0	2	3
USA	10	9	1	2	0	22
Total	52	50	41	15	15	

Examples of successful realization of these end uses are demonstrated by the following case studies.

3.1. Wildlife

Steep sides and poor sediment development can limit wildlife through limiting aquatic macrophyte growth rate and extent [19] and macroinvertebrate community abundance and diversity [20, 21]. Conversely, the steep-sided pit walls above the water surface can provide valuable habitat for species that are adapted to such conditions, such as bighorn sheep *Ovis canadensis* around Sphinx Pit Lake (Figure 2). In British Columbia, Canada, Mountain Goats *Oreamnos americanus* can be found seeking refuge on the benches of abandoned mine pits.

The presence of endangered species of plants and animals has been recorded in a number of sandpit lakes in the Třeboň Basin of the Czech Republic after discontinuation the sand mining [22]. In Denmark, gravel pit lakes were found to be important habitats for communities requiring oligotrophic conditions which widely got lost in natural lakes due to cultural eutrophication [23].

The sandpit lakes afford an area for new populations of water and marsh plants that are found locally and also regionally within Central Europe. 14 tree species and 59 herbaceous plant species with a minimum cover of 5% were documented on the 11 monitored sandpit lakes. The sandpit lakes were classified as important biotopes according to the European Union guidelines. Endangered species of vascular plants occur in many sites in the sandpit lakes such as *Illecebrum vercillatum*, *Lysimachia thyrsiflora* and *Lycopodiella inundata*.

Similarly, these littoral flora have been found as an important component of the waterfowl environment. Forty two species of water birds were recorded in the sand-pit lakes belonging to 10 orders [24]. Sand-pit lakes were found to represent biotopes that can serve as refuges for the endangered species occurring in the Třeboň Basin Biosphere Reserve: little bittern *Ixobrychus minutus* and great reed warbler *Acrocephalus arundinaceus* and potentially for other bird species that may not be as endangered.

Figure 2. Bighorn Sheep taking advantage of steep habitat created around Sphinx Pit Lake, Alberta, Canada

3.2. Fishery

Fisheries represent a common and often incidental, end use for pit lakes where water quality is reasonable to good. However, pit lake fisheries require more than simply water quality, with habitat and food sources being important determinants of a successfully sustainable fishery [25, 26]. Lower nutrient status often limits primary production and thus fishery food availability [27, 28]. Conversely, generally good water quality that contains elevated COPC that may biomagnify, may actually present a risk to end users such as higher orders of consumers as birds and mammals, reptiles [29-32] and also human game fishers and hunters [33, 34]

This may limit use of pit lakes with low productivity for a fishery. This was reported for well remediated (including neutralized) German pit lakes in former lignite mines [35] and Swedish gravel pits [23]. However, pit lakes can support a diverse biodiversity of fishes if well managed [36].

Beneficial socio-economic development of the Milada pit lake in Northern Bohemia, Czech Republic initially led to high densities of cyprinid fishes resulting in eutrophic water conditions [37]. As a result, lake management has featured an extensive stocking and harvesting ecosystem biomanipulation management programme since 2005 focusing on lower densities of fish, dominated by piscovores. For example, larger individuals of the traditional game fish pike *Esox lucius*, zander *Sander lucioperca* and wels catfish *Silurus glanis* perch is still the most abundant predatory fish in the lake. However, dying aquatic macrophyte vegetation as the lake fills means that there may be insufficient habitat for perch egg laying unless artificial habitats are used [38].

3.3. Recreation

Pit lakes have afforded local populations with both passive and active recreational opportunities in a number of cases studies. Pit lake recreation may be water-based, terrestrial only when water quality is poor or safety issues remain, or a mixture of both [39]. Planning pit lakes for recreation involves a number of factors that must consider human health and safety. Water quality is a key concern [40], nonetheless safety aspect of bank steepness [12], shoreline stability [41] and appropriate water depth [42] must also be considered. However, strong competition between sites and communities can develop in new lake districts. In order to avoid failure of investments in new infrastructure for recreational end use of the pit lakes, regional concepts and regional collaboration of all stakeholders is needed [43-45].

In Alberta, Canada, about 25 open cut coal mine pits have been converted to pit lakes that are now used as recreational fisheries and as central features around which hiking trails have been created (Figure 3). Quarry Lake, an abandoned coal mine on the edge of the Rocky Mountains, is a popular destination for angling and hiking [46, 47]. For East Pit Lake (resulting from coal mining and filled primarily with groundwater), water-quality monitoring and habitat assessment demonstrated that the lake was suitable for establishing an arctic grayling recreational sport fishery. Alberta

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Environmental Protection awarded TransAlta a reclamation certificate for the lake in 1994 [48]. Similarly, Lovett and Silkstone pit lakes were created in the 1980s and were used as prototypes for the creation of other sport fisheries from mine pits in the region [49], such as Sphinx Lake which was created two decades later. In British Columbia, Canada, former mine pits and tailings ponds at a copper mine have been converted to sport fisheries that now host a popular fishing derby [50].

Figure 3. Public end use access sign at East Pit Lake in Alberta, Canada

Buzzacott and Paine [51] reviewed 157 existing pit lake dive parks worldwide and argued for converting additional mine pits to inland dive parks. The main benefits of such dive parks are that they reduce pressure on sensitive dive sites, especially for diver training which can entail accidental contact with the substrate, and that they have a longer season due to warmer temperatures than the ocean in many locations, which enables divers to maintain their skills and social interactions in the off season.

New lake districts formed in the eastern part of Germany from lignite mining in the Lusatian and in the Central German lignite mining district [52]. For the majority of these lakes, recreation is one of the intended end uses, often the main one. Lake Senftenberg (lake 4 in Figure 7) became rapidly a highly frequented destination for weekend recreation after its filling and neutralization in the 1970s since the distance to the city of Dresden (ca. 550 000 inhabitants) is only ca.60 km and there were very rare alternative options for water related recreation in that region. The increasing attractiveness of Lake Senftenberg and the more and more filled new pit lakes in its neighborhood is reflected by an increasing number of visitors staying overnight (Table 2). Connecting Lake Senftenberg and the new pit lakes by canals and water gates (Figure 4; see also Figure 7) allowing for direct travel from lake to lake by boat certainly contributes to this attractiveness. In the Central German lignite mining district, Linke and Schiffer [53] found that the popularity of the lakes for recreational purposes is strongly related to the distance of the lakes to the two major cities in the region: Leipzig (ca. 580,000 inhabitants) and Halle (ca. 240 000 inhabitants).

Table 2. Comparison of tourist data for facilities of the Zweckverband Lausitzer Seenland Brandenburg (Germany) in 1996 and 2018

	1996	2018
One day visitors	ca. 700,000	ca. 800,000
Visitors staying overnight	19,500	62,500
Guest-nights	96,700	268,000
Average duration of stay of overnight visitors	4.96 days	4.29

Figure 4. An excursion boat entering the water gate between Lake Senftenberg and Lake Geierswald (lakes 4 and 7 in Figure 7)

In Australia, the Shire of Collie has a population of 9,104 and mine pit lakes in the Collie Pit Lake District [54] present recreational opportunities for both residents and tourists to the area. Historically abandoned and unrehabilitated Black Diamond and Stockton Lake are currently being used as recreational areas [42] (Figure 5). Already rehabilitated and more contemporary Lake Kepwari is proposed for relinquishment as a recreational facility [55] but is often illegally accessed [56].

Of approximately 20% residents randomly surveyed, 58.5% had used the pit lakes in the last two years [40]. Both males and females used the pit lakes with a slightly higher percentage of males using the lakes for recreational purposes (Table 3). Of the water-based activities, more time was spent water skiing and boating than other activities. Types of activities undertaken at each lake did not differ by gender; except at Lake Kepwari where males undertook all of the listed activities, whereas females undertook mainly swimming, wading, boating and picnicking. A difference in lakes was that most camping occurred at Lake Stockton which has a large parking area nearby and least boating at Black Diamond which is a small lake with no defined boat launching areas.

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Figure 5. Water skiing on abandoned mine pit lake Stockton in Western Australia

Table 3. Types of recreational activities undertaken by pit lake users at each of the lakes (n= number of respondents; values in table are percent of respondents reporting a given use) [40]

Activity	Black Diamond (n=127)	Lake Kepwari (n=32)	Stockton Lake (n=123)	Other (n=6)
Swimming	83.5	53.1	72.4	50
Kayaking/Canoeing	15.0	3.1	15.4	33
Wading	31.5	21.9	24.4	17
Boating	6.3	9.4	40.7	0
Water skiing	2.4	3.1	27.6	0
Marroning	11.0	9.4	12.2	33
Picnicking	42.5	40.6	47.2	50
Camping	20.5	9.4	30.9	33.3
Walking	7.9	9.4	2.4	0
Fishing	1.6	0.0	1.6	17
Other	7.1	28.1	11.4	0

3.4. Water Source and Storage

Pit lakes are infrequently used as a water source. Potable uses are typically limited by the presence of alternative, pre-existing water supplies, and by often low water quality resulting from elevated geochemical reactivity in void shell rocks and any mine waste backfill materials.

There are several anthropogenic lakes used as fresh water reservoirs in the Czech Republic, especially in large gravel sand mines in southern Moravia near Ostrožská Nová Ves village [57]. Drinking water is also abstracted from bores immediately around the historic gold mine Wedge Lake pit in the Goldfields region of Western Australia [13] (Figure 6). Pit lake and immediate surrounds groundwater is low in salinity, hardness and nitrates and is combined with groundwater from a bore field near the treatment plant.

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Figure 6. Wedge pit in arid Western Australia is used as a municipal potable water supply for the nearby town of Laverton

Several pit lakes in the Lusatian Lignite Mining District (Germany) are used for flood protection and water storage. The stored water is used for regional management of the water balance. The storage capacity of those lakes is provided in Table 4. Figure 7 shows the location of the lakes. The overall storage capacity of German pit lakes used for flood protection and water storage is $264x10^6$ m^3 [58]. Although this is only a small part of the total volume of German pit lakes, its availability is regionally very important.

Table 4. Storage capacity and total volume of the pit lakes used for flood protection and water storage and shown in Figure 7 (Data provided by Landestalsperrenverwaltung des Freistaates Sachsen, Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft, Landesamt für Umwelt Brandenburg)

Lake	Lake number	Total volume (in case of total filling) 106 m^3	Storage capacity 106 m^3	Surface area (in case of total filling) km^2
Senftenberg	4	102	20.5	10.3
Sedlitz+Geierswald+Partnitz	6+7+9	212+98+134	15.0	14.2+6.5+11
Knappenrode	21	18.1	6.4	2.86
Burghammer	22	35	6.0	4.82
Lohsa I	23	23.3	5.8	3.42
Dreiweibern	24	35	5.6	2.94
Lohsa II	25	97	60.5	10.8
Bärwalde	26	173	25.0	13.0

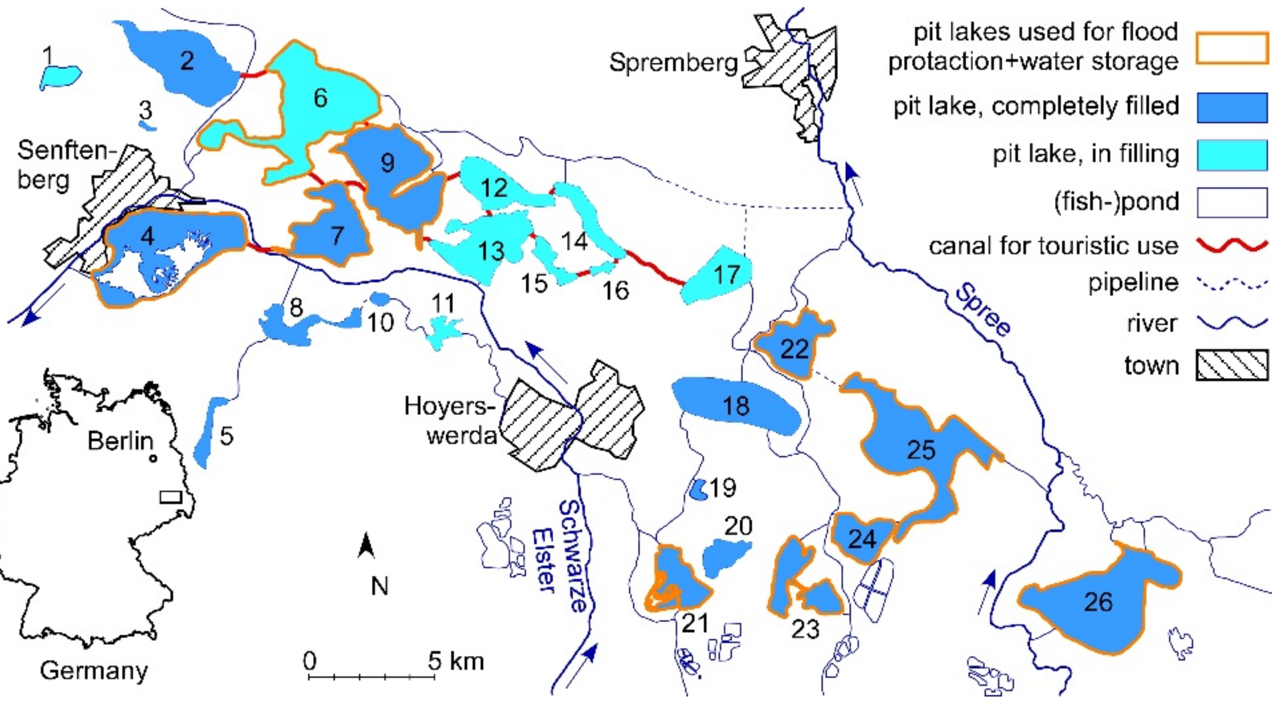

Figure 7. Pit lakes of the central part of the Lusatian Lignite Mining District (Germany). Pit lakes marked by orange lines are used for flood protection and water storage. Canals and water gates connecting pi lakes for touristic use are indicated by red lines

3.5. Waste Containment and Treatment

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Pit lakes often present an attractive solution for disposal of mine wastes, especially Potentially Acid Generating waste rock and tailings. Subaqueous disposal of mine wastes is considered a best practice in many jurisdictions [59, 60] because it limits the mine waste's contact with oxygen and thereby restricts the potential for generation of sulfuric acid from residual sulfides.

The void of the former lignite mine Großkayna (Central German lignite mining district) was partially backfilled with industrial wastes. The wastes mainly consisted of ashes from lignite combustion. Waste materials from the production of nitrogen fertilizer were also deposited among the ashes leading to ammonia concentrations >300 mg/L in pore waters. A pit lake (Lake Runstedt; volume 54×10^6 m^3, area 2.33 km^2, maximum depth 33 m) was established on top of the waste material by deviating water of river Saale. By controlling neighboring pit lakes water levels decant of the lake and transport of fluids from the waste into groundwater is prevented [61]. Hypolimnetic aerators are used to enhance nitrification in the hypolimnion while denitrification was proved to occur in the littoral [62].

Creation of water-capped tailings or end pit lakes is also a strategy for permanent storage of fluid fine tailings (FFT) from oil sand processing [63-65]. Both fresh and process-affected waters are used for filling. One function of such lakes is the passive bioremediation of toxic chemicals such as naphthenic acids and related organic acids [66, 67]. Mixing between the MFT (mature fine tailings) that oil sands refining produces and the overlying water cap can be prevented by a sufficient depth of the water layer [68]. Moreover, the lake must not recharge aquifers that are in contact with other sensitive water bodies. However, regulators have not yet approved this concept, and there are remaining uncertainties such as the rate of detoxification and how microbial metabolism and gas production will affect long-term water quality.

Springer Pit Lake is a mine pit at the Mount Polley Mine, a copper mine in B.C., Canada (Figure 8). The pit lake stored water and tailings after a tailings storage facility embankment breach on August 4, 2014. Storing tailings in a pit void was considered Best Available Tailings Technology for geotechnical stability [69]. Between August 2014 and August 2015, tailings supernatant water and mine runoff were diverted to the pit lake. Upon resumption of mining in August 2015, mill process water and tailings were also deposited in the pit lake. The pit lake was then used as the primary feed source for water discharge following treatment. After a few months, Springer Pit Lake provided sufficient passive water treatment for the active water treatment plant to be switched to "passive mode", meaning that mechanical and chemical additions to the water treatment plant were switched off and only monitoring instruments were left active [65, 70]. Water quality in the pit lake followed predictable trajectories [71] and was suitable for discharge to the receiving environment, without active treatment. At present, the pit lake is being drawn down, and tailings are planned to be removed from Springer pit to allow mining to resume in the pit. At mine closure, approximately 15 Mt of potentially acid forming (PAF) waste rock will be placed into the pit, which is a regulatory requirement.

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Figure 8. Springer Pit Lake and Dewatering Infrastructure at Mount Polley Mine, BC, Canada

4 Discussion

We found beneficial end use type and outcome varied dependent upon climate and commodity; but equally important were social and political dynamics. We also found that initial optimism about likelihood of end uses being successfully realized often failed to meet stakeholder expectations over longer post-closure terms.

Mining company interest and willingness to engage in the repurposing of pit voids as pit lakes with beneficial end uses requires a view to innovation outside of typical day-to-day mining activities. Similarly, regulators must have views open to different closure outcomes than they may be used to and that regulation may permit [72]; with some beneficial outcomes presenting higher risks than more traditional approaches to closure (backfill, fencing, etc.). Third parties, be they investors, community groups or research organizations may assist in this process [73].

4.1 Determinants of end use success

Our review has shown that there are general attributes of pit lake shape, location, type and their closure management that can lead to successful end uses becoming realized.

Some pit lakes have been shown to provide good habitat conditions for conservation of significant bird life and plant species. Unlike many natural lakes that are now eutrophied by human activities, many pit lakes, especially those from inert geological materials such as sand and aggregate mining, are oligotrophic which may help prevent out-competing periphytic algal from smothering the plants. Although hard-rock mine pit sides are often steep relative to natural lakes, the low stability of their sandy host geology and shallow depth means that littoral areas of some pit lakes, such as in sand quarry operations, may be extensive [74].

Water quality is often the limiting factor to establishing wildlife values in a pit lake; low pH and elevated metals may make both in-lake fisheries and aquaculture using off-take water unsuccessful or unacceptably high risk for a commercial venture [75]. Conversely, good pit lake water quality may

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be deteriorated in ultra-oligotrophic and unproductive pit lakes by nutrients from uneaten fish food and from fish waste in in-lake aquaculture operations, or by high nutrient concentration discharge [28] (Figure 9).

Figure 9. Nutrient-rich discharge to a dystrophic Western Australian coal pit lake from an adjacent aquaculture farm has been found to improve water quality

Although water quality is key to a successful pit lake fishery; habitat and food availability/quality are also necessary for a successful sustainability [25]. For example, substrate for egg spawning [76] or woody and rocky debris for protective shelters [26] were necessary habitat features. The shoreline slope and length are also recognized as important habitat characteristics, with micro-topography of the benthos such as varied depths advised to create more diverse habitat. Shallow wetland areas can also be constructed near inflow areas to mitigate nutrient inputs into the main lake body [77].

Even if fisheries are able to establish, then contaminant uptake by fish must be thoroughly assessed [29]. Nonetheless, in locations where the potential for contaminant uptake is high but fish health is maintained, sport fishing or ornamental fish farming can still be employed. Contaminant accumulation can also be reduced through shorter duration fish cultivation (i.e., using fast-growing fish species) and artificial feeding [78].

In the case of direct water contact, recreational uses of lakes will be primarily defined by location and access to human habitation. Exceptionally low turbidity due to low phosphorus availability and, thus, very little plankton growth can make pit lakes very attractive sites for diving. Dive parks and other water-based recreational uses may be more valuable in regions that do not already have natural lakes in which to recreate or where existing lakes are limited in their recreational opportunities e.g., by size, shape and depth; or by competing uses such as wildlife values.

Pit lakes can only be successful as a water source if the lakes are of sufficient volume and water quality appropriate to the end use [57]. Water volume and quality may be inter-related in high net evaporation areas where higher water quality/volume end uses may be unsustainable [3]. Water balance and associated water quality modelling can be useful in determining the long term success of these end uses [79].

Waste deposition requires conditions that limit the transport of contaminants into other components of the environment. Depending on the geological setting and the nature of mine wastes disposed of, mine closure will need to consider a number of transport pathways, including: the atmosphere, surface water, groundwater and biota. Sealing the mine void shell and capping of the waste and hydrological control may be required, depending on ambient conditions.

4.2 *Achieving end use success*

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A risk-based approach is recommended for determining which end use option might be appropriate in pit lake closure planning; even if no end use is then proposed. A Human Health and Environmental Risk Assessment (HHERA) approach is more appropriate if the assessment is solely risk-focused e.g., where end uses are not intended e.g., Canadian North Environmental Services [80]. However, any end use assessment should also address opportunities and not solely focus on risk; which is likely to increase as opportunity does {Vandenberg, 2015 #37}{McCullough, 2009 #60}. There are various approaches suitable for determining opportunity in concert with risk. A SWOT (Strength-Weakness, Opportunity-Threat) approach is an appropriate ways to assess these options in a risk/opportunity-balanced framework.

By understanding potential risks, early and coordinated research across relevant spatial and temporal scales can be strategically undertaken [81]. Planning and management strategies can also be implemented by mining companies and government agencies so that post closure, pit lakes can be used as recreational areas or for other end uses. To ascertain potential for health risks, it is then necessary to determine how often and for what purposes people are using the lakes for recreation so that the level of exposure to physical, chemical and biological characteristics can be estimated.

Such stakeholder engagement should be early, regular and transparent in order to achieve best outcomes of end uses that both match stakeholder expectations and also practicalities [15]. However, such stakeholder aspirations may also change over time, and end use planning should both expect and accommodate these changes [82].

5. Conclusions

As with many mine closure outcomes, examples of end use development as a closure strategy are rarely published; and even more so when they are not successful [83]. In particular, academic research (often by graduate and post graduate students) on abandoned mine pit lakes end uses often does not progress past industry reports and academic theses and dissertations [73]. We collated information on geographic and physical attributes and pit lake end use outcomes to determine what lessons might be gleaned to improve pit lake closure practice and outcomes.

Common attributes and reasons that led to successful closure outcomes as end use developments included not only a multi-disciplinary contribution, but also a trans-disciplinary approach to planning (Figure 10). This contribution had to involve technical experts from allied disciplines and worked best when these experts had experience with other pit lake successes.

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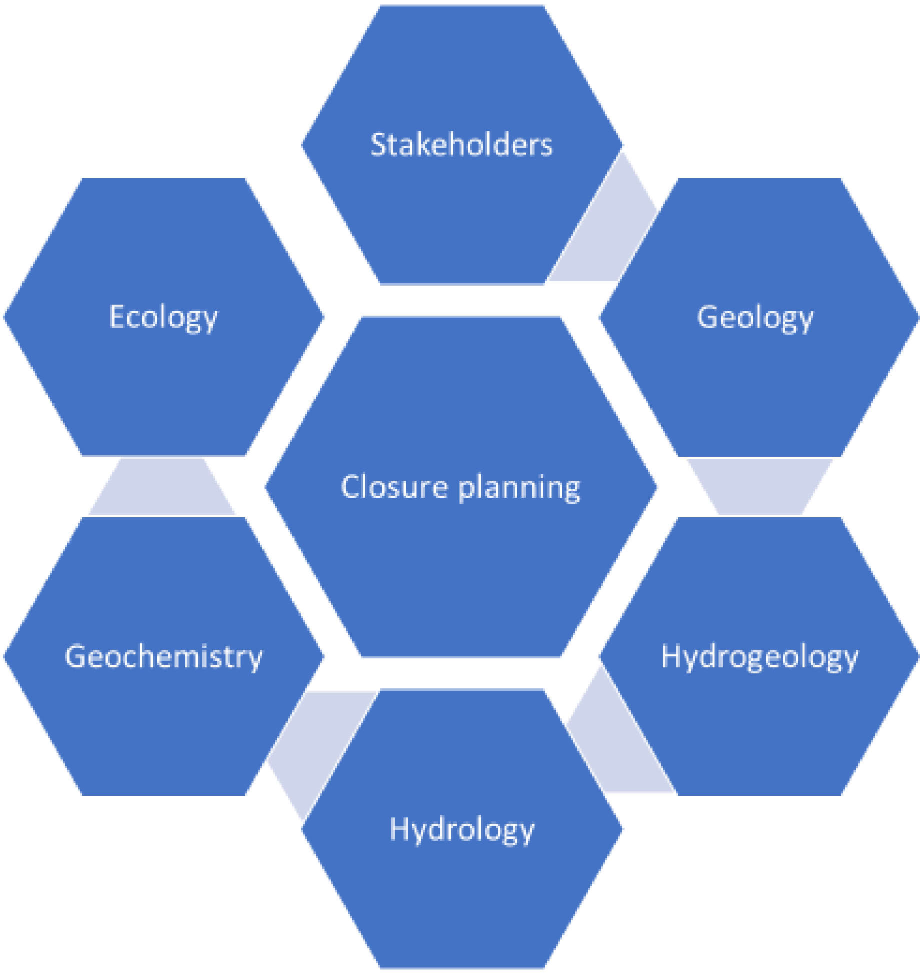

Figure 10. A trans-disciplinary approach to opportunity planning of pit lakes.

Furthermore, a number of practices were noted to lead to successful outcomes. These practices include: early planning and incorporation of closure considerations into mining plans; early and regular engagement with regulators and other stakeholders (and vice versa); consideration of long term effects of climate and regional socio-economic dynamics; good water quality of source waters (through good waste management and also fewer geochemical issues in mine waste and pit void shell exposures); and relatively significant contributions of good water quality to the pit lake e.g., through rapid filling[84-86] or ongoing flushing such as flow-through [55, 87].

Different end uses require different water quality and habitat structures. While low productivity is favored for recreational diving, a sustainable fishery requires higher productivity. Dense standings of macrophytes, favored by large littoral zones and shallow depth may hinder swimming. Therefore, not all potential uses can be combined in every single lake, in particular in the case of small lakes. However, if there several lakes close to each other or large they may allow for multiple uses spatially-separated e.g., recreation and nature conservation. Good design and management (considered guidance, smart location and infrastructure development, particularly access roads and exceptionally attractive recreational facilities) allows for directing activities and managing intensity of use [88].

Since water depth is a decisive factor for the occurrence of seasonal thermal stratification and the amount of oxygen available in the hypolimnion during stratification, the shaping of final mine void and the defined final water level have considerable influence on the recycling of phosphorus (so-called internal loading; see Nürnberg [89]) and other chemicals from the sediment. In other words, future water quality problems can be mitigated by appropriate design of the final mine void.

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