LANDFORM DESIGN INSTITUTE

Mining with the end in mind:

Landform design for sustainable mining

POSITION PAPER

MARCH 2021

The Landform Design Institute at a glance

The Landform Design Institute (LDI) is an independent, not-for-profit organization collaborating with the international mining community, regulators, and Indigenous and local communities. It was created in 2019 to develop and support a global community of landform design practitioners.

Landform design is an emerging, integrated, multidisciplinary process to successfully reconstruct mine land. It allows industry, regulators, and communities to work together to manage costs and risks, minimize liability, and produce progressively reclaimed landscapes with confidence and pride. Done well, landform design leads to a positive mining legacy — it is a pillar of sustainable mining.

The LDI has a five-member Board of Directors and a Technical Advisory Panel of 15 representatives with experience in all aspects of landform design and mine reclamation around the world. They represent a range of disciplines and roles and responsibilities.

The Institute's vision is that all mining occurs with the end in mind. The end is defined as successful reclamation — that which satisfies the needs of all involved: the mining company, the regulator, Indigenous peoples, and local communities. Each mining landform and each mine site receives joint signoff upon completion.

The vision is achieved through the mission, which is to make landform design routine in the mining industry worldwide by 2030 by developing clear how-to guidance, providing education and training, and supporting the global community of practitioners.

In its first year, the LDI produced a number of useful products and it is now fully established. In its second year the LDI initiated a gap analysis and is continuing to produce podcasts, the *Quarterly* newsletter, university lectures and hot-topic video vignettes, and technical reports. We are building a community of practitioners, attracting individual and student members as well as corporate members and sponsors. This document defines and makes the case for landform design, setting the basis for an understanding of this emerging global discipline.

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Position Paper 2021-01

March 2021

Acknowledgements

The concept of landform design was conceived by Dr Norbert Morgenstern, Professor Emeritus at the University of Alberta. This new discipline has been developed and field-tested over the past 25 years by landform design teams comprised of mine staff, Indigenous peoples, local communities, regulators, consultants, contractors, and academics, all working together and drawing on their training, their experience, and on published information from around the world. The Landform Design Institute appreciates the observations, insight, and ideas from those participating in the gap analysis and the thoughtful feedback provided by its members on an advance draft of this document.

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The LDI acknowledges that its head office lies in unceded territory of the Coast Salish People.

Suggested citation: LDI. 2021. Mining with the end in mind: Landform design for sustainable mining. Position Paper 2021-01. March 2021. Landform Design Institute. Delta, BC, Canada. 78 pp.

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For corporate memberships, sponsorships or donations, contact i**nfo@landformdesign.com**. Corporate membership includes all the advantages of student and individual membership, plus access to all online course materials and prominent logo placement on all Institute products. Sponsorship includes all benefits of corporate membership plus formal recognition as a Landform Design Institute sponsor in publications, communication products, and event displays. The Institute will be seeking sponsorships with an annual donation of $25,000, $50,000, or $100,000 (each receives equal recognition). One-time donations of any amount are also much appreciated.

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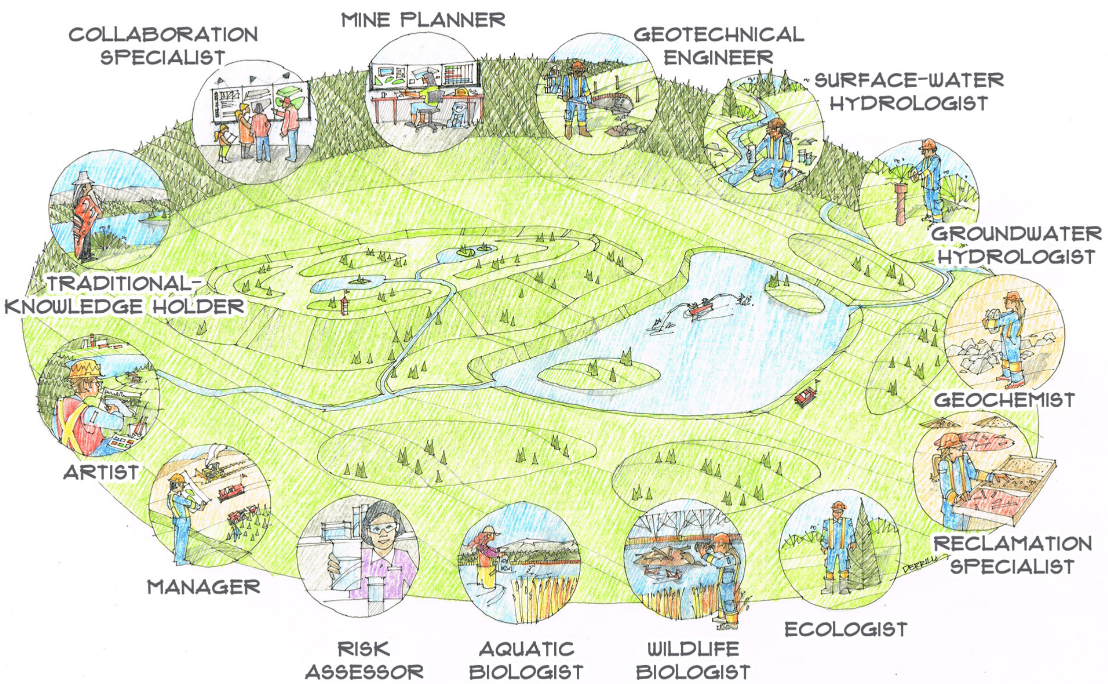
Summary

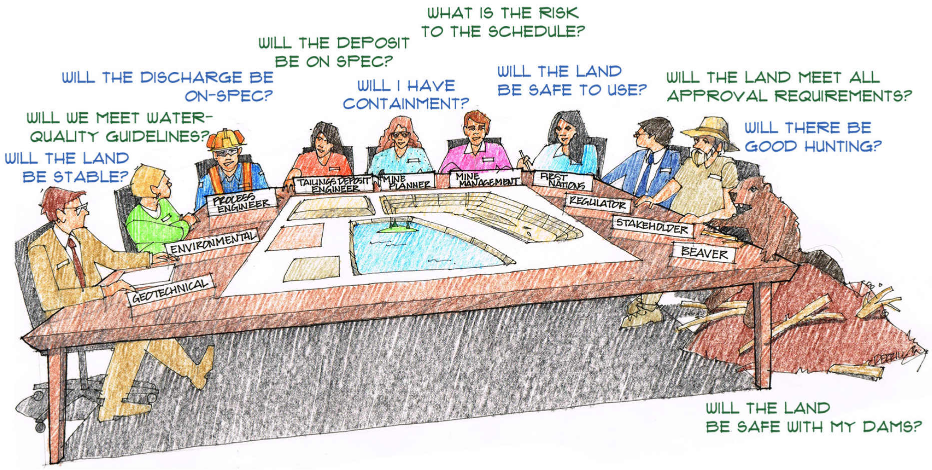
This position paper sets out the rationale for landform design, the emerging global practice of reconstructing mine landscapes responsibly and successfully. The Landform Design Institute (LDI) was established in 2019 to provide the knowledge, education, and support that landform design practitioners need to build truly sustainable mining landscapes, and to make landform design routine in the mining industry worldwide by 2030.

Conceived 25 years ago, landform design is a discipline that has grown out of the concept of mine reclamation, which started in earnest in the 1960s and evolved under the rubric of progressive reclamation. Landform design has helped mines, regulators, Indigenous peoples, and local communities collaborate on creating mining landforms and landscapes that reliably and economically meet agreed-upon goals and objectives. But while much direction exists on what needs to be done and why, little practical guidance is available on how to implement landform design. Landform design practitioners require the tools to transform the mining industry into a genuinely responsible steward of post-mining landscapes. A central source is needed to generate and distribute useful and educational resources.

Collaborate



Plan

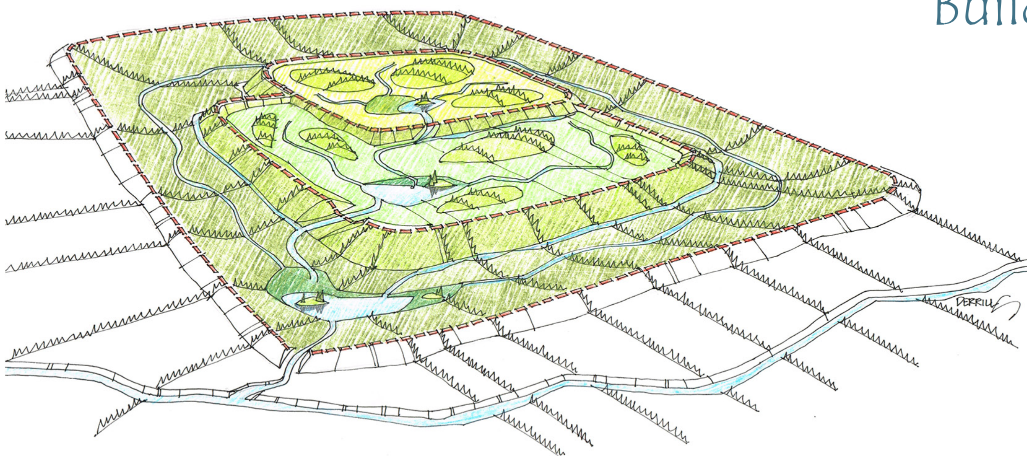


At its most basic level, landform design is mining with the end in mind. The process begins even before mining starts. This is the first of the 12 principles of landform design (see Appendix A). While the need to turn waste rock and tailings facilities into something resembling natural landforms is widely acknowledged, truly sustainable mine closure requires incorporating and implementing these measures into mine operations even before breaking ground. This will result in better long-term landscape performance and lower costs, reduced liability, and less risk. Mines will more effectively meet their commitments to successful reclamation.

The Institute will provide the tools practitioners need to make landform design a common practice. It will advocate for the integrated, multidisciplinary and collaborative approach integral to this transformation. For each mine, critical to this undertaking is the formation of a dedicated team of experts working together over the life of the mine and beyond: development, operations and progressive reclamation, final reclamation, and aftercare. Currently, many see the "mining cycle" as a linear process of discrete phases. In fact, these activities are concurrent during every phase of mining. That's effective landform design.

> *Despite billions of dollars invested in mine reclamation and the expertise and hard work of thousands of people, conventional reclamation continues to fall short of achieving signoff and returning access to local communities.*

Build

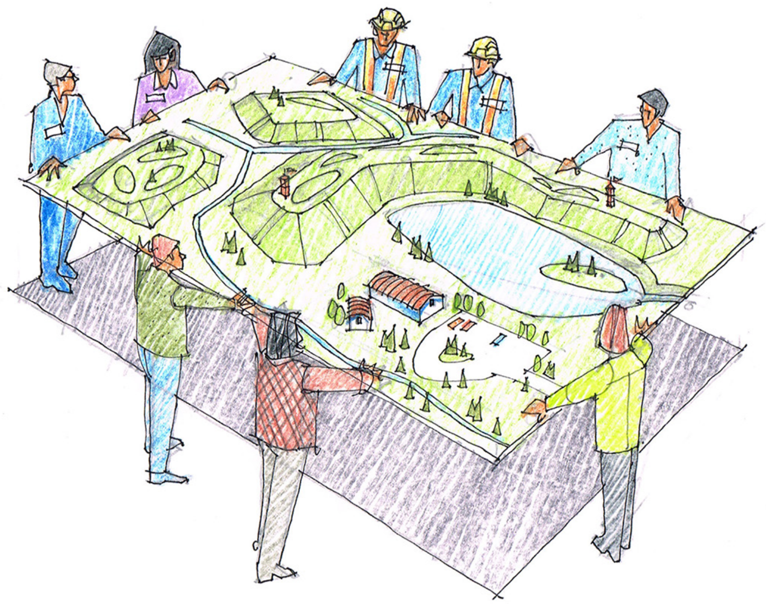


In developing its work plan, the Institute initiated a gap analysis to investigate how the current international state of practice in landform design and mine reclamation compares to the commitments made by mines and the expectations of regulators and Indigenous and local communities. The gap analysis has included consultations with experts and an overview of the available literature. The main finding is that despite billions of dollars invested in mine reclamation and the expertise and hard work of thousands of people, conventional reclamation continues to fall short of achieving signoff and returning access to local communities; hence the impetus for landform design to break this impasse. The other findings and themes from the gap analysis provide the foundation for this position paper and form the basis of the Institute's strategy and business plan.

Thanks to this research, and the input of our Board, Technical Advisory Panel, members, and other experts in the field, the ways the Institute can best provide leadership and apply resources are emerging. The need is urgent. Instituting landform design is required to ensure the industry will be equipped to handle the resource demands of the 21st century, while respecting the ever-growing expectation that mining become a fully collaborative and responsible undertaking and ensuring mine landscapes are being reconstructed sustainably. This document attempts to set out a common framework and definitions for the Institute's future offerings.

Introduction

Since its inception, the discipline of landform design has helped mines, regulators, Indigenous peoples and local communities collaborate on the creation of mining landforms and landscapes that reliably and economically meet agreed-upon goals and objectives.[1] It is becoming an essential component of successful reclamation, sustainable mining, and global sustainable development.[2] This integrated and multidisciplinary approach to designing and reclaiming mining landscapes – or mining with the end in mind — is progressing on numerous independent fronts around the world. While useful direction on what needs to be done and why is widely available,[3] little practical guidance is available on just how to do it, and no central repository exists of useful and accessible[4] supportive documents and illustrative case histories. Mining with the end in mind means cultivating a shared vision for the reclaimed landforms and landscapes that remain long after mining has finished and the extracted resources consumed.



INTEGRATION / WORKING TOGETHER

The Landform Design Institute (LDI) was founded in 2019 to formally develop and globalize this new discipline of landform design and to support an international community of landform design practitioners. Building on an initial 2002 survey of what was promised by mine reclamation versus what was delivered on the ground,[5] and drawing on recent interviews and a high-level literature review, the Institute is completing a gap analysis in 2021 to identify ways to address the shortcomings of the status quo through the production of technical publications, including reports, databases, tools, training videos, and lectures.

In the course of the gap analysis, it became clear that to foster the global community of practitioners, we needed to improve the landform design framework and better define the language of the discipline. This position paper updates and refines dozens of definitions related to landform design and the concept of successful reclamation in an effort to provide a common vocabulary and process.

Building on the results of the gap analysis, the Institute has created a detailed five-year plan[6] with three focus areas: developing how-to resources, providing education and training, and supporting the global landform design community.

A pressing need exists to close the significant and ubiquitous gap between what mines are promising for their reclaimed landscapes and what is being delivered. From a financial point of view, all mines already focus on all phases of mining as part of their need to keep mines profitable and valuable to shareholders. The next step is to fully understand the requirements of post-mining land uses, how much it will actually cost,[7] how that can be achieved through sound strategic and operational decision-making, and how to work collaboratively with all those affected.

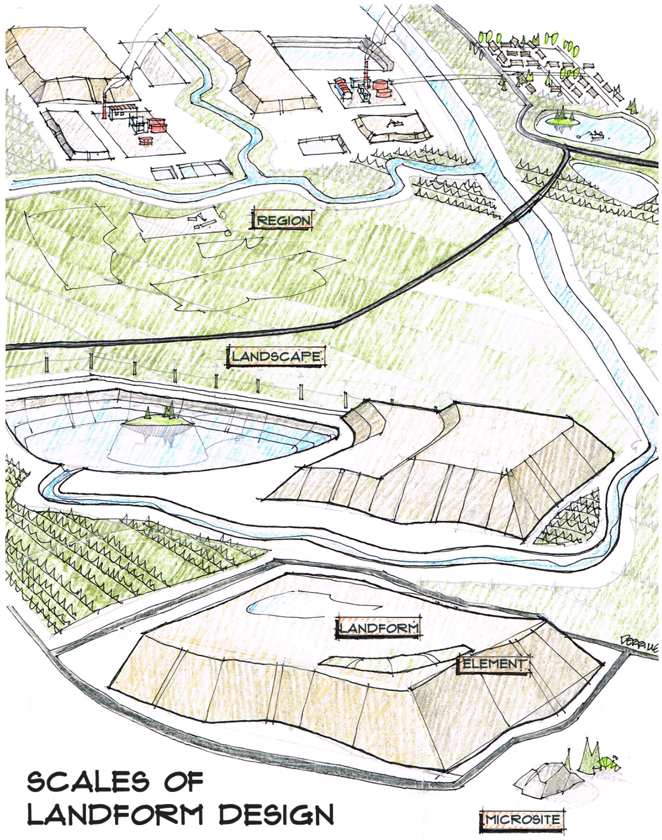
Much comes down to integrating planning, design, and construction of mining landforms and landscapes — across spatial and time scales, across disciplines and communities, across the multitude of mining activities and teams, and across the financial system — to deliver financial returns to shareholders and society (through royalties, taxation, and employment) while creating safe, useful, and ecologically productive reclaimed mine land for all.

The appendices that follow are in many ways the heart of the position paper. They build on hard-won lessons to form a solid foundation for the Institute's work and landform design in general. We look forward to reviewing our progress in 2030 to see how the content of these tables and descriptions have evolved with the work of the Institute's members.

Defining a mining landform

A landform[8] is a distinctive topographic feature created by natural or artificial processes. Together, landforms make up the surface of the earth. A mining landform[9] is constructed through mining activities. Examples include a waste rock storage facility, tailings storage facilities, mined-out pits / pit lakes, and site-wide drainage systems. Together, mining landforms make up a mining landscape[10] (often delineated by the mine site's property boundaries).

Most mining landscapes comprise up to two dozen contiguous mining landforms, which also serve as the basic units of planning and design (see Table 1). Every square metre of the mining landscape belongs to precisely one mining landform. Most mine sites / mining landscapes are also part of a mining (or ecological or socioeconomic) region. Table B-1 (Appendix B) provides a concise set of terms used by the Landform Design Institute. Table C-1 provides additional information on these spatial scales.



Many practitioners have learned to think about their sites as a collection of mining landforms. This approach taps into centuries of geomorphological and ecological literature, studying the processes by which natural landforms evolve, and integrating and applying this knowledge to the design of mining landforms. These landforms are logical management units for the design, operation, decommissioning, reclamation, and aftercare of mines.

By thoughtfully delineating boundaries, responsibilities can be assigned to ensure no areas of the mining landscape are orphaned. Experts can debate where to draw these boundaries. For example, consider a toe ditch (toe creek) at the base of two waste-rock storage facilities: does it belong to the first or the second facility, or is it part of its own landform unit in the surface water drainage system? The answer is that it doesn't matter. What matters is that the design team deliberately and carefully chooses logical boundaries and then manages each landform and the mining landscape as a whole.

Some practitioners even eschew the traditional facility names that describe the original function (such as South Waste Rock Facility 1 or Tailing Storage Facility 7) in favour of more visionary names that signal their end state (such as Moose Mountain, Gateway Hill, Sphinx Lake, or Nikanotee Fen). This telegraphs to all just what is being constructed and what will remain long after the mining has moved on, integrating the creativity and skills of all involved in pursuit of a common vision.

Tailings dams, and tailings facilities more generally, deserve special mention here as they provide unique challenges to landform design teams. The recent spate of tailings dam failures internationally has sharpened the need for more thorough tailings management at every stage, including aftercare.[11] The Institute will build on existing work related to landform design for tailings facilities[12] to address unique issues, such as how to reduce risks of failure, how to delicense tailings facilities that no longer serve as dams, how to reduce and manage the erosion of the downstream face of tailings-sand dams, and how to design for acceptable long-term risks related to ponds. Many issues will continue to challenge landform designers concerning tailings and tailings facilities, and new guidance is being developed.

The Institute embraces the argument that waste rock storage and tailings facilities should best be considered landforms from the very beginning of planning and designing the mine. The reclaimed landscape performance is often dictated by the internal structure of the landform (controlling such things as geochemistry, groundwater flow, gas fluxes, and post-reclamation settlement). Opportunities are lost and costs and risk increase if design is left until the bulk fill placement is done.

However, waste rock and tailings facilities are increasingly seen as features that should be turned into landforms only after construction. The Institute proposes beginning this process much earlier. From the very day the first haultruck-load of mine waste is deposited, or the excavation of a new pit begins, a new landform is created; mountains become pits, prairie flats become hills. Designing and building them as landforms from the outset (when most of the critical decisions are made) results in better long-term landscape performance and lower costs (operational and maintenance), reduced liability, and less risk, helping mines meet their commitment to successful reclamation.

Two smaller scales are also considered: landform elements (such as ridges, wetlands, access roads, mounds, lookout towers) and several kinds of microsites (an ecological term for features such as shade under a boulder, roughened topography, and piles of coarse woody debris). Table C-1 provides a list of spatial scales, more detail about the levels of designs, and the kinds of mining equipment used in their construction. These scales are nested within one another and are important for the integration of closure design. They have an impact on the flow of water, wildlife, people, trucks, and materials throughout the mine site and ultimately the reclaimed landscape.[13]

Landform grading (sometimes called "landforming") is sometimes confused with landform design but is a tool that is often employed by landform designers. It was developed in the 1980s and 1990s for heavy civil and mining applications.[14,15] As such, landform grading is well developed and becoming more commonly used in mining for three main purposes — it fosters orderly surface water drainage from mining landforms, it helps landform designers embrace Louis Sullivan's architectural design principle that "form follows function," and it can be used to deposit and regrade mining landforms so they look (and perform) similar to the natural hillslopes in the region.

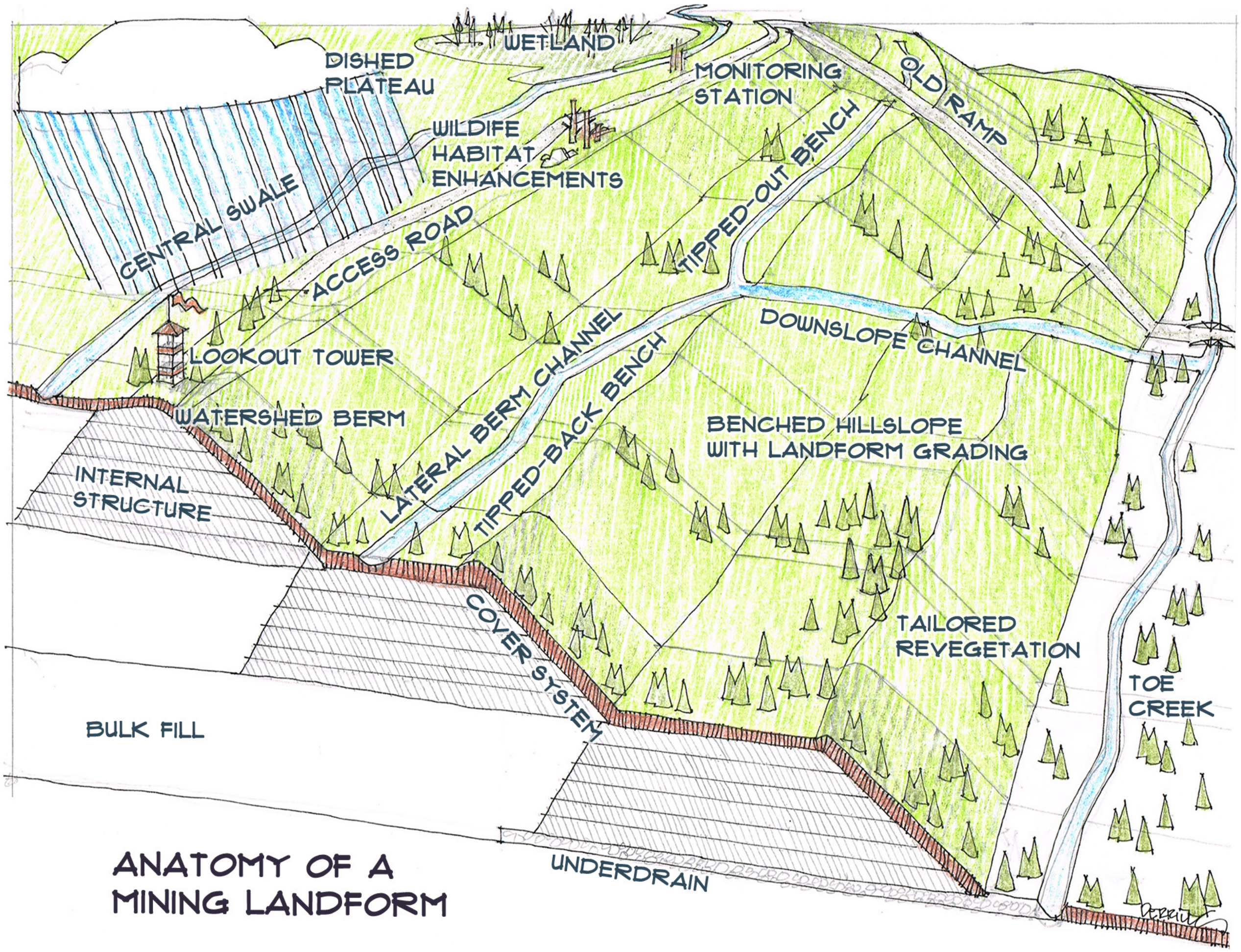
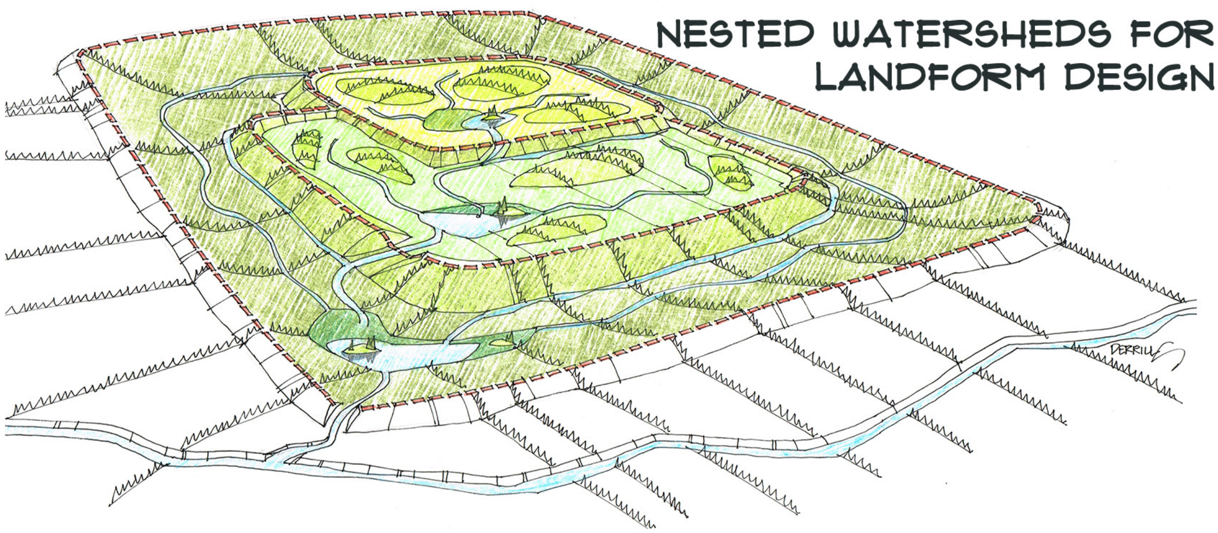


Table B-2 provides a list of common mining landforms, and the list of mining landform types is presented in Table B-3.

Table 1. Nested spatial scales in landform design

Scale	Nominal linear dimension[16] (m)	Description, example
Region	100,000	A grouping of mines in a valley or region
Lease / landscape / domain	10,000	A single mine lease / property
Landform	1,000	A single mine facility: mined-out pit, stockpile, waste rock or tailings storage facility
Landform elements	10 to 100	A single designed feature on a landform
Microsite	1	Small features on a landform typically included for a specific reclamation purpose



Landform design is similar to watershed design, given that the surface watershed is a fundamental unit of landscape performance.[17] The watershed design approach does offer some significant advantages, but most mining landforms have numerous watersheds, and working with surface-water watersheds (defined by topographic boundaries) can easily be confounded with groundwater watersheds (defined by groundwater flow divides that are more difficult to map and change with time). While landform designers embrace watershed design, they typically define their management units according to discrete mining landform units for practical operational purposes.

Aside from being structures that permanently store mine waste, landforms and landform elements are designed for specific functions and land uses. Landforms may be required to physically isolate mine wastes; direct, store, attenuate, or mix runoff waters; generate clean water for downstream users; protect aquifers; provide aesthetic skylines; host roads, trails, powerlines, and pipelines; contribute to regional wildlife corridors; or accommodate a trapline. As in any design, evaluating the desired functions for the landform, managing the potential for conflict with other desired objectives, accounting for practicalities, and making trade-offs are central responsibilities of the team.

Defining landform design

Landform design is the integrated, multidisciplinary design and construction of mining landforms and landscapes, directed by a dedicated team working with different mine operations groups and others over the life of the mine and beyond. The focus is on achieving successful reclamation —reclamation that will steadily fulfill the specific vision, goals, and objectives of the mining company, the regulator, and Indigenous and local communities. It achieves signoff on completion, confirming that all mining operations and reclamation for a landform or landscape have been satisfactorily completed, and that the residual risks are acceptable to all parties.[18] Landform design allows all parties to work together to manage costs and risks, minimize liability, and produce progressively reclaimed landscapes with confidence and pride.

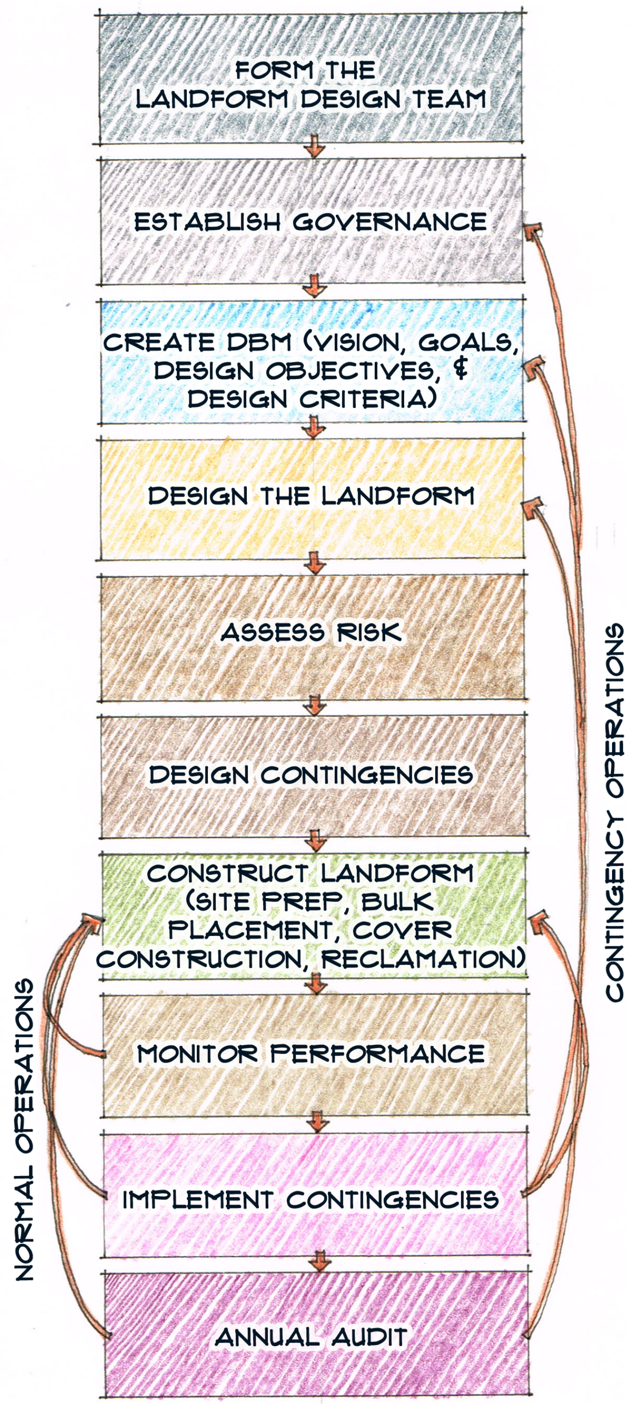
The design of a landform starts before mining begins (or as soon as practical for mines already in production), and continues throughout each period: development, operations and progressive reclamation, final reclamation, and aftercare.

In essence, landform design is about integration:

- Integration across spatial scales – the mining region, the landscape (mine site), the landform, the element, and the microsite
- Integration across disciplines – mine planning, geotechnical, surface water, groundwater, geochemistry, soils, vegetation, wildlife, traditional knowledge, and others
- Integration across time scales – pre-mining, construction, operations and progressive reclamation, decommissioning and post-closure reclamation, and long-term aftercare
- Integration across communities – mining industry, practitioners, regulators, and Indigenous and local communities[19]
- Integration within the mine – management, project design, engineering, technical consultants, reclamation operations, and maintenance operations
- Integration across the financial system – mines and mining companies, and local, state, and federal governments

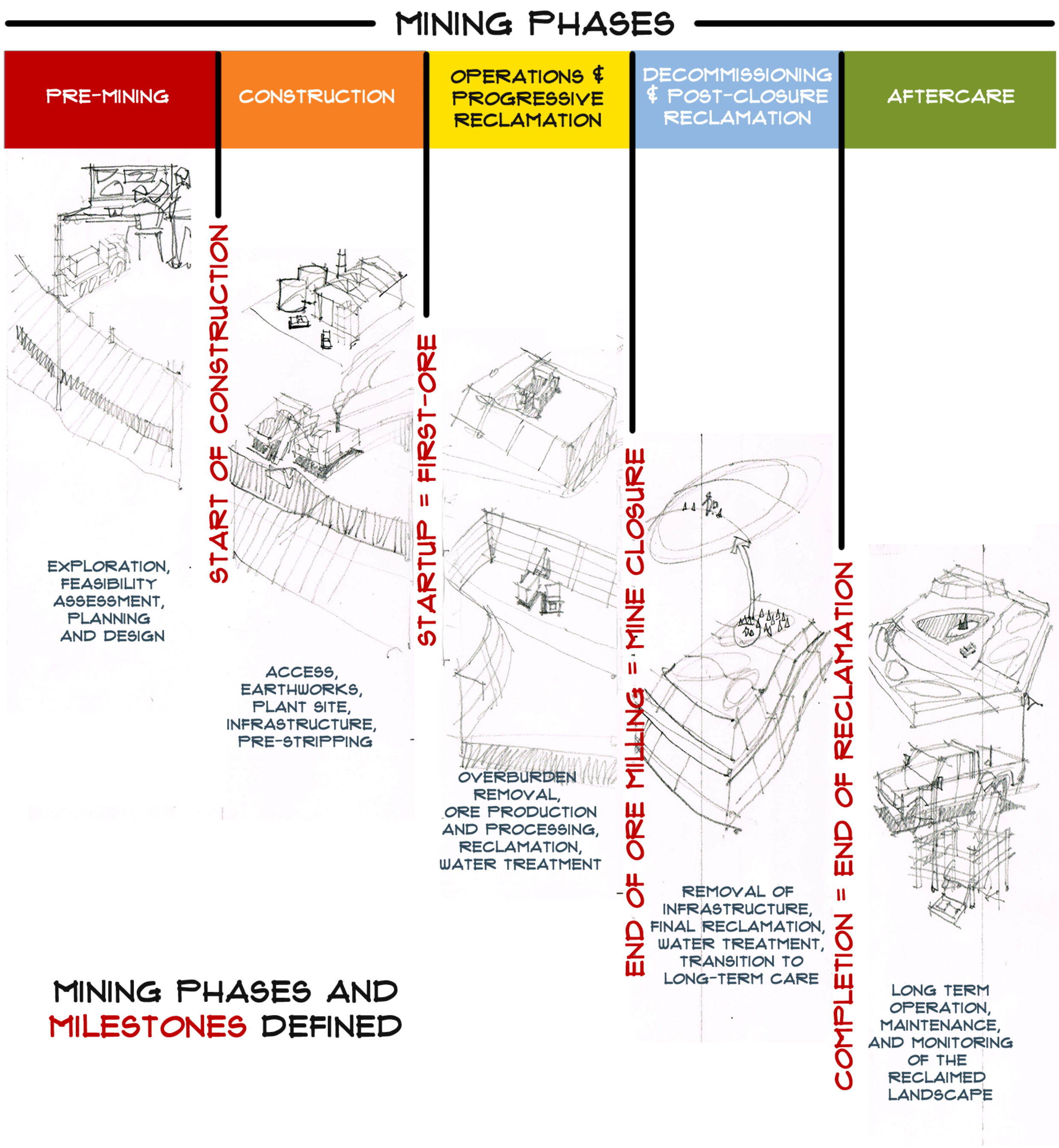
Myriad publications offer various accounts of the "mining cycle." Most describe mining as a linear process of discrete phases, including exploration, development, operations, and reclamation. The process can last several decades. Many assume reclamation occurs only after mine operations have ceased. In reality, all these activities are generally concurrent during every phase of mining.

The Institute has embraced a modification of the oft-used mining-cycle timeline, employing a more useful system of five phases and four milestones, as shown in the "mining phases" figure. While it is meant to apply to the whole lease, it can be adapted to individual landforms (or groups of adjacent landforms). The definitions in Appendix B provide more detail. Each of the milestones is akin to a project management gate. Each involves obtaining approval (or signoff) from mine management, the regulator, and Indigenous and local communities.



LANDFORM DESIGN SIMPLIFIED WORKFLOW

In recent years, mine closure has evolved from an identifiable singular event into either the indeterminately long period after mining operations or a phase that includes all reclamation activities, such as those featured in the production of a mine closure plan. This reclamation-based "closure" framework has led some to erroneously assume that no activities related to reclamation need to be considered or implemented until the final years of mine operations. This is an unfortunate consequence of the term itself. The Institute argues that a change in terminology is needed, and that "closure" should revert to being considered a point in time rather than a phase.[20]



Many mining companies focus on some form of regulatory signoff for completion of the closed and reclaimed mining landforms or more commonly the mine landscape as a whole. Most expect to recover their bond as part of the release of liability and obligation, which seldom if ever comes (see Table 3). It is now generally recognized that each mine needs to be reclaimed to a safe and suitable post-mining use with access for local communities. At the same time, it is clear that almost all mines will require aftercare in the form of monitoring and maintenance for decades or centuries.[21]

Reclamation, which is closely related to landform design,[22] is a term that requires some clarification, as the definition of reclamation can vary widely internationally:

- **Mine reclamation** can include restoration, rehabilitation, and remediation,[23] and is the operational activity after bulk mine-waste placement in a landform. It involves regrading, placement of cover materials, and revegetation, along with the monitoring and maintenance associated with this activity. For most mines, mine reclamation involves establishing ecosystems suitable for wildlife habitat and human use. But at many mine sites, it can involve other land uses,[24] including such uses as industrial, commercial, and residential development, farming, ranching, or recreation. The Dutch have used the term reclamation to refer to the construction of polders and dykes on natural deltas and fans for the past 2000 years to create terrestrial landscapes (mainly agricultural land uses but also urban).[25]
- **Progressive reclamation** is carried out during active mining on landforms that have reached their design configuration and are no longer required for active mining operation. Ideally a mine site will already be mostly reclaimed at mine closure.
- **Progressive access** refers to allowing users access onto reclaimed land while mining activities proceed elsewhere on site.
- **Successful reclamation** fulfills the vision, goals, and objectives and achieves signoff by the mine, its regulator, and Indigenous and local communities.
- **Mine closure** is a specific point in time rather than a phase or collection of activities — it is the date of the final ore processing (which can be months to years later than the end of mining if ore stockpiles are processed).

While some of these definitions are at odds with common usage in the literature and regulations, the proposed definitions provide better clarity and reduce the chance of confusion. They are likely to continue to evolve.

Common misconceptions

This position paper is intended, in part, to correct some misconceptions about landform design:

- *"Don't worry... we've got plans to turn it into a landform when Operations is finished with it."* Instead, it is more useful and much more economical to consider mining facilities as mining landforms from the very beginning. Most of the design decisions are made before the first earthworks. Leaving it to the end precludes most options and leads to expensive and only partially effective remediation and retrofits.

- *"We'd love to do landform design, but it's not a greenfields site — the waste-rock facilities are already under construction."* It is never too late to apply landform design principles to mining landforms and mining landscapes. Indeed, the greatest application in coming decades will be to existing landforms and mine sites, whether in construction, operation, reclamation, or during aftercare.
- *"Landform design is geomorphic design."* In fact, geomorphic design is a tool that landform design teams can employ. While it's desirable for mining landforms to have geomorphic attributes of natural landforms (notably through landform grading), not all mining landforms will have features that can be designed to change in a predictable manner — this is an area of active research and full-scale experimentation.
- *"Landform design is mainly about aesthetics, making waste-rock piles look natural."* Landform design is much broader, and may or may not include visual aesthetics.[26] It comes down to meeting commitments set out in the design basis.
- *"Landform design is too new, it's unproven, we can't be expected to employ it."* Actually, it's been practised for 25 years on dozens of landforms (and under different names on hundreds of mining landforms). The general approach is derived from Ralph Peck's 1969 geotechnical observational method,[27] which is employed worldwide for tailings dams in particular. While much remains to be learned, landform design is an opportunity rather than a burden, a process for setting and achieving agreed-upon visions, goals, and objectives.
- *"Calling it a landform is enough, like calling a garbage dump a landfill."* Yes, some jurisdictions refer to waste-rock facilities as landforms, but the terminology here is not meant for public relations; it describes a holistic process and will work alongside the many old mining terms that will be used for decades to come.[28]
- *"Landform design is just design."* Landform design is a phrase that includes planning, design, construction, decommissioning, reclamation, and aftercare. It is the responsibility of a multidisciplinary, integrated team to shepherd each mining landform and each mining landscape throughout its life history. It's more than design.[29]
- *"Progressive reclamation is just nice to have."* On the contrary, progressive reclamation is a key component of operations, allows a "trial by doing" opportunity to reduce costs and risks, and helps build trust between all parties so that reclamation and operations remain on track to meet agreed-upon goals and objectives. Accordingly, we have redefined the conventional operational period of a mine as "Operations and Progressive Reclamation."[30]

The case for landform design

The case for broadly instituting landform design begins with a review of historical practices and the current state of practice. Mine reclamation only started in earnest in the 1960s and 1970s, when mines were much smaller and expectations more modest.[31] At the time, reclamation was rudimentary, and involved grading the slopes of mine waste facilities to constant grades (or approximate original contours), sometimes with benches, placing a thin layer of growth media, and revegetating with agronomic grasses mostly to control erosion.[32] The need to manage surface water was recognized, but implementation varied widely and was usually overlooked. Even these modest beginnings present a steep learning curve; today, cover design[33] and revegetation are mature reclamation technologies. Although acid rock drainage has been problematic for mining landforms for millennia, methods to control it only arrived in the 1960s, and in recent years the application of these technologies has matured but continues to evolve.[34]

With ever-larger mines and ever-increasing expectations and commitments, a significant gap has developed between what mines have promised to achieve on reclaimed lands and what is actually delivered. This gap has persisted since the 1960s. Work by various groups over the past 15 years[35] has clarified what needs to be done, at a high level, and what activities need to take place. But mines still struggle with setting clear goals and objectives, with working with local communities, with executing timely progressive reclamation, and with achieving signoff on completion of reclamation. Despite billions of dollars in investments, thousands of dedicated practitioners working hard for years, and usually agreeable landscape performance, few mine sites are ever fully reclaimed, fewer result in the return of financial assurance, and users are typically barred indefinitely from even well-reclaimed land.[36] What seems to be missing is the how-to aspects and a framework for successful reclamation.

The international mine reclamation community is highly fragmented — by jurisdiction, by speciality, by commodity, and by climatic region.[37] There is a dearth of reclamation textbooks, and training is typically local and region-specific. Much of the know-how resides in individual mines. Considerable sharing of expertise does occur, mainly through published conference papers and mine tours. But little unified work occurs.

A more multidisciplinary approach, one that builds on the current approach to mine reclamation, means tapping into engineering tools, setting design parameters, producing formal designs, identifying and addressing failure modes, constructing mining landforms that will be easy to reclaim, and bringing the whole weight of proper governance and engineering rigour to bear. It begins with the vision, followed by the setting of a design basis, various levels of design, stamped issued-for-construction drawings and specifications, construction monitoring, and production of as-built reports to demonstrate that the landform was built to the design. It ensures that members of the landform design team accept professional responsibility for the results.

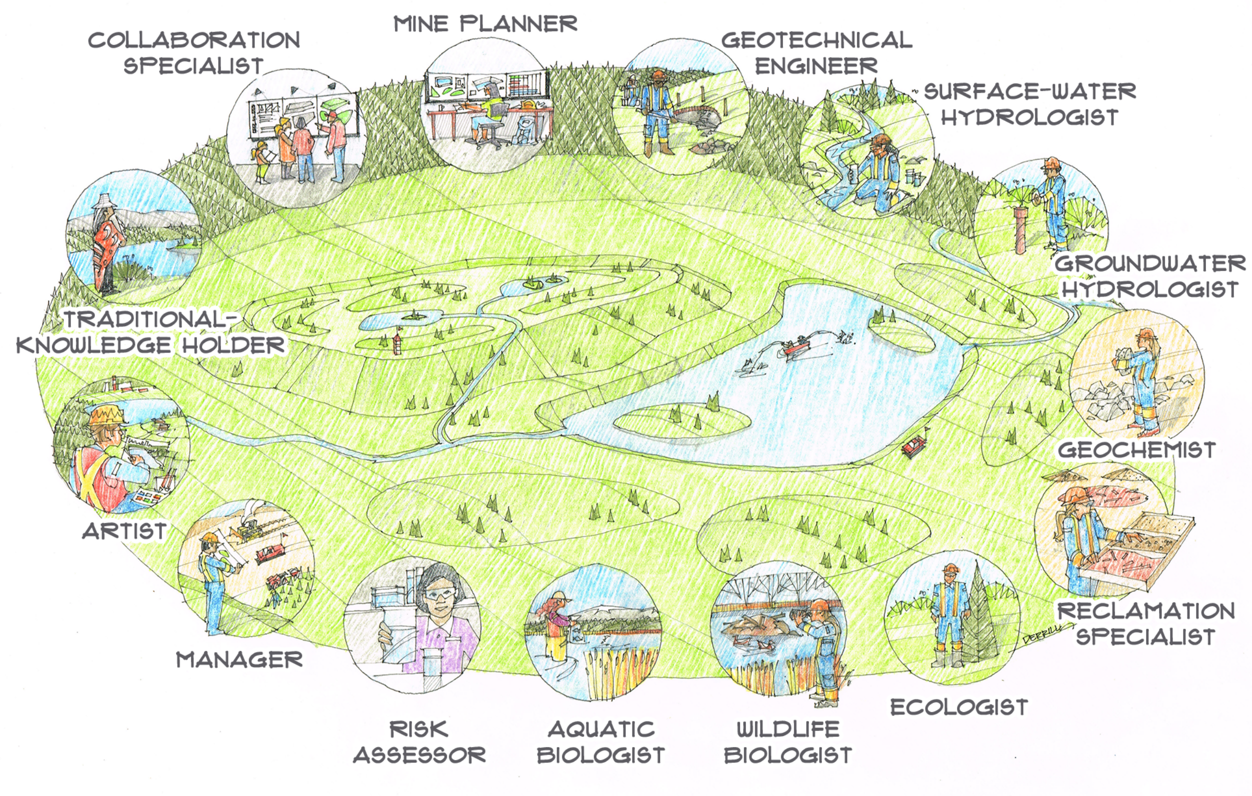
The main stumbling block is residual risk. There are always residual risks to any reclaimed landform or mining landscapes — the risk that the landform won't perform as intended, that people or animals might be injured or become sick, that the vegetation won't grow as vigorously or as fast as intended, or that it is replaced with less-desirable species. Additional risks exist: that people can't use the land as intended, that the performance doesn't meet the regulatory requirements for geotechnical or erosional stability, or that the water quantity or quality fail to meet regulatory requirements. A further complication is the dynamic (not static) nature of all landscapes. Good performance today is not a guarantee of good performance tomorrow. More than 200 potential failure modes are recognized.[38] Each can react with others in complex pathways — many mine sites are the size of modest cities and exhibit complex, unpredictable behaviour. People's desires change, regulations change, expectations change, and climates change. Accordingly, the Institute will be examining and pioneering new risk management methods related to landform design as part of successful reclamation.

The next most fundamental issue is that the required performance is rarely well defined, and that in almost no cases are the regulators inclined to sign off on the reclamation or take on liability. Mine owners, recognizing they are liable for the performance of the reclaimed landscape, are usually unwilling to give control to a regulator (though transfer of liability to a new mine owner is common). Mine owners are often reluctant to spend millions or billions of dollars on mine reclamation or seek signoff. While these two issues are framed in terms of the interaction between the mine and the regulator, they also apply to Indigenous and local communities who will inherit the risks. Regulatory policy is often lacking or wed to old paradigms.

A new approach, a structured, multidisciplinary approach with a clearly stated vision, goals, and objectives, is required for successful reclamation. As well, a transparent mechanism to manage the residual risk, ideally developed up front, is critical.[39] The framework of landform design provides such a system and has been successfully employed at numerous projects in recent decades. These successes bolster the case for landform design.

The practice of landform design

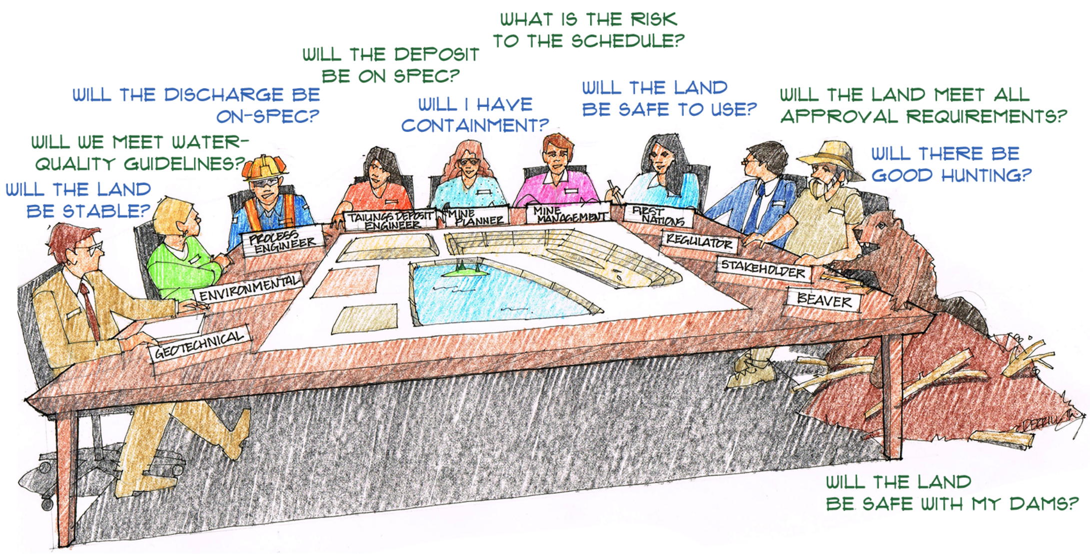
Landform design is a multidisciplinary approach to reconstructing mine landscapes with confidence and pride. At the outset, it involves the establishment of a landform design team, which typically includes representatives of 6 to 12 disciplines. A lead designer takes overall responsibility for the design and construction. Ideally, the team is formed before mining begins, but for most mines it will be assembled partway through. Larger mines may form several landform design teams for different areas of the mine site or for different kinds of landforms. Often these teams have overlapping membership. There is typically a core team (responsible for mine planning, geotechnical, surface water, groundwater, geochemistry, soils, vegetation, wildlife, and risk assessment[40]) supplemented by specialists such as limnologists or aquatic biologists for some types of landforms. Additional specialists, as shown in the illustration, are often required. The team will work for decades, often with considerable turnover. Table 2 provides the roles and priorities for the various members. Appendix E supplies additional details. Table 2 outlines the responsibilities of this team, working alongside the traditional mining teams.



THE LANDFORM DESIGN TEAM

Table 2. The roles and priorities for the landform design team

Mine phase	Mine teams	Landform design teams
Exploration and pre-mining	Permitting and development team ☐ Regulatory and community engagement ☐ Gaining approval / permit ☐ Operational feasibility ☐ Agreed upon post-mining land use plan ☐ First mine closure and reclamation plan	Landform design team Specialists from mine planning, mine operations, local communities, regulatory, geotechnical, surface water, groundwater, vegetation, soils, wildlife, safety with a cohesive vision of meeting mining commitments efficiently at a landform scale Working alongside the mining teams with the priorities of following the process for each landform ☐ Governance ☐ DBM ☐ Design ☐ Risk assessment ☐ Contingencies ☐ Construction ☐ Reclamation ☐ Monitoring ☐ Performance assessment
Start of construction		
Construction	Mine development team ☐ Roads and infrastructure construction ☐ Water management ☐ Pre-stripping ☐ Starter dyke construction ☐ Plant-site construction ☐ Economical mine plan	
Startup = first ore		
Operations and progressive reclamation	Mine operations team ☐ Mine plan – efficient mine waste management ☐ Geotechnical design / dam safety ☐ Operational water management ☐ Progressive reclamation and access ☐ Environmental monitoring and compliance	
End of ore milling = mine closure		
Decommissioning and post-closure reclamation	Reclamation team ☐ Removal of infrastructure and plantsite ☐ Final reclamation ☐ Surface water management and treatment ☐ Access support for land uses	
Completion = end of reclamation		
Aftercare, custodial transfer Relinquishment or abandonment	Corporate mine legacy closure team The Crown / state / local communities ☐ Monitoring ☐ Future permit approvals ☐ Safety (water quality / trafficability / geochemistry) ☐ Stability ☐ Performance (vegetation, wildlife, water) ☐ Supporting agreed-upon land uses ☐ Environmental compliance	



EACH MEMBER OF THE DESIGN TEAM BRINGS DIFFERENT OBJECTIVES

The basis, or factors, for landform design varies in some cases significantly from discipline to discipline; but there are some common themes which influence the design:

- Mine plan and waste material volumes
- Climate and climatic regime
- Post-mine land use
- Watershed characteristics: geological and hydrogeological
- Waste physical properties and geometry (e.g., constructability, settlement, slope stability)
- Waste chemistry (e.g., reactive versus non-reactive, metal leaching versus acidic seepage)
- Cover material characteristics and availability
- Timeframes for establishment of stable and productive landforms
- Governance model and regulatory setting
- Site access and constructability

Many of these design factors are common to those outlined by the International Network for Acid Prevention[41] for cover systems.

Historically, target land uses were assigned as the last stage of design — an output rather than an input, or more often simply declared by well-meaning mine management.[42] But one would obviously design a landform differently if it were to be used for a residential subdivision than for wildlife habitat. Mining with the end in mind means the vision and suite of post-mining land uses should be developed with Indigenous peoples and local communities before mining starts.

Climate is a major filter, not only because it affects the land uses and vegetation, but plays a central role in erosion, soil development, and even the foundation conditions (for example, residual soils in tropical regions versus colluvium in semi-arid zones and glacial tills in temperate zones). Many techniques and the expected performance in one climate region can't be translated to other regions, and all designs and construction approaches can be influenced by climate cycles and climate change, often in unexpected ways. Design guidance for accommodating climate change is starting to become available[43] and is a topic under consideration by the Institute.

Landform design is typically documented by the production of the following sequence of activities and design documents:

- An agreed-upon design basis, documented in a design basis memorandum (DBM), which lays out the vision, goals, design objectives, and design criteria, and includes the regulatory requirements and formal commitments with Indigenous and local communities. The evolution of the DBM is closely tracked.
- A detailed landform design – documented in a landform design report and issued-for-construction (IFC) drawings and specifications that are signed off by professionals – provides specific construction details and specifications for all activities for the landform, including site preparation, initial construction, bulk materials fill, regrading, placement of covers, revegetation, and monitoring / maintenance. This is similar to the process for tailings dam design and construction.
- Clear construction records, documented as a formal as-built report and drawings, detail the history of the landform and ensure the landform was constructed to specifications.
- Ongoing monitoring of the landscape performance that follows the landform observation, maintenance, and surveillance (OMS) plan, which is in turn based on the DBM. Timely decisions are made when contingencies need to be enacted.
- Documentation that demonstrates that the landform is performing as intended, with signoff by the landform design team, communities, and the regulator.

The mining company, the regulator, and Indigenous and local communities use these records to determine when construction and reclamation activities are complete. A formal completion signoff is then carried out, the landform moves into a funded aftercare program, and there is ongoing access for the intended land uses.

Mining companies often state that they are building the reclaimed landscape for future land users, and often this means Indigenous communities. But for successful reclamation, mines need to be building the reclaimed landscape in cooperation with Indigenous communities, recognizing their economic, social and cultural values and priorities. This is part of the new concept of "co-reclamation"[44] that the Institute will be supporting and helping the global landform design community implement.[45]

Below are the steps of landform design done well:

- A comprehensive life-of-mine plan[46] completed prior to start-up and executed over the life of a mine that remains on schedule and on budget. Ideally the plan would be fixed,[47] but in practice, the potential for major changes is anticipated, embraced, and to the degree practical, factored into designs and plans. Progressive reclamation, progressive signoff, and progressive access are fully integrated with ongoing operations.
- An effective collaboration process (involving the mine, the regulator, Indigenous and local communities) that begins before mining starts, continues beyond custodial transfer, and entails meaningful ongoing dialogue with all interested parties.
- A steady level of progressive reclamation, including resloping, cover placement, revegetation, creek and river establishment,[48] monitoring and maintenance. Low variation in levels and types of annual activities allow for a steady and experienced reclamation workforce and consistently level budgets. The advantage of this approach is that progressive reclamation and monitoring of performance present an important opportunity for proof of concept of reclamation techniques.
- Land that achieves signoff. After a few start-up years, equal amounts of land have been disturbed, reclaimed, and signed off every year. The work, while still requiring innovation and creativity, becomes a routine part of the mine's annual operating cycle. At closure, the last disturbed land is reclaimed and signed off promptly.
- Reclamation that is indistinguishable from operations, taking advantage of large mining equipment for some tasks, and smaller (often contractor) equipment for finer tasks.
- Research that is carried out in advance of mining and continues during mining to provide timely answers for detailed reclamation designs and activities. Much is learned from studying natural analogs, cover systems, and vegetation trials, ideally within instrumented watersheds designed for reclamation research.[49]
- Goals that are achievable, practical, environmentally sound, and sufficient to ensure reasonable landscape performance.[50] The goals of the mine, regulator, and Indigenous and local communities are coincident but evolve over time.
- The evolution of monitoring and maintenance into aftercare. It is planned for, agreed to by all parties, executed in a timely and economic manner, and funded by the mine.

- A useful landscape that fits into (and supports) local ecosystems and economies. Changes to terms of land uses or properties are understood and accepted by all.
- Trust among the mine, regulator, and Indigenous and local communities throughout the life of the mine. Earning and maintaining trust between all groups is central to success.
- Sufficient funds for the regulator to immediately step into the role of the mine manager and reclaim the land to the standards in the design basis memorandum (DBM) if needed.
- Acceptance by all parties and pride in the new landscape.

Gaps in current practice

As part of developing a strategic plan for the next five years, the Institute initiated a gap analysis to answer two questions:

- How does the current international state of practice in landform design and mine reclamation compare to the commitments made by mines and expectations of regulators and local communities?
- What are the opportunities arising from the identified gaps that the Institute can address by providing an enhanced landform design framework supported by "how to" guidance?

This work complements and echoes an initial survey of what would become landform design in the 1990s.[51] That work involved visiting 77 mines in North America armed with a list of dozens of questions. This initial survey was conducted during a period when reclamation practices were maturing rapidly and closure planning was still a novel concept.

The current gap analysis involves structured interviews with seasoned landform design and reclamation specialists who were asked to answer the following five open-ended questions:

- What are mines promising for their reclaimed landscapes? What are they delivering?
- What is holding mines back from achieving these promises / returning the land?
- Where is the best information to learn about successful reclamation (recommended publications, websites, tools)? Whom else should we talk to?
- Do you know of any mine reclamation projects that have been signed off (by a regulator and / or local community), or achieved a return of financial assurance, or were returned to the government?
- What "how to" guides or tools should the Institute produce that would help you with landform design and successful reclamation? Or what questions should be answered?

The interview results were tabulated and supplemented by a literature review. The assessment is ongoing, the initial results are provided in Table 3, and some observations are presented in Table F-1. To complete the gap analysis, a focus of the LDI this year will be expanding the reach of the gap analysis interviews to additional interested groups and individuals. The main findings and themes to emerge from the analysis influenced this position paper. Some key areas of current conditions from the gap analysis represent opportunities for the Landform Design Institute to provide leadership and resources. These opportunities form the basis of the Institute's strategy and business plan.

Table 3. Findings and opportunities for landform design and mine reclamation

Findings	Ideal conditions for successful reclamation	General opportunity	Proposed Institute projects and activities
Financial drivers of progressive reclamation are poorly quantified and reclamation is often deferred, sometimes permanently. Current business frameworks favour making extravagant commitments during permitting, then deferring progressive reclamation as long as practical.	Decision-makers (at mines and the regulator) have full understanding of the financial framework and use this to make business decisions and reclamation regulatory policy.	Improve the business framework related to mine reclamation and landform design and focus on the profile of liability and risk throughout the life of a mining landform.	Set out a method to better manage liability and risk throughout the lifetime of a landform. Lay out the business case for informed progressive reclamation. Collect case histories of successful reclamation using landform design and its benefit to the mines.
Governance generally involves a mine's environment department focusing on meeting permit conditions and annual reporting. Those responsible for reclamation suffer from ineffective or partial governance structures; reclamation is often a bolt-on activity.	Mine reclamation and landform design are integral parts of mining operations with an accountable executive.	Improve landform design governance model.	Provide guidance on successful landform design governance models and activities including individual roles and responsibilities. Provide guidance on more holistic mine planning activities. Develop how-to guidance on the five axes of integration in landform design.
Integration between mine operations and reclamation teams is often lacking. There is a focus on geotechnical and short-term planning / operations and closure landforms, and priorities are assigned as a separate task to the reclamation team.	Full integration, with useful and timely landform designs, and teams working together to optimize mine economics and meet the requirements of regulators and local communities.	Enhance integration between mining teams. Develop techniques to have just one plan (see below)	Develop guidance on how to work as a multidisciplinary team.

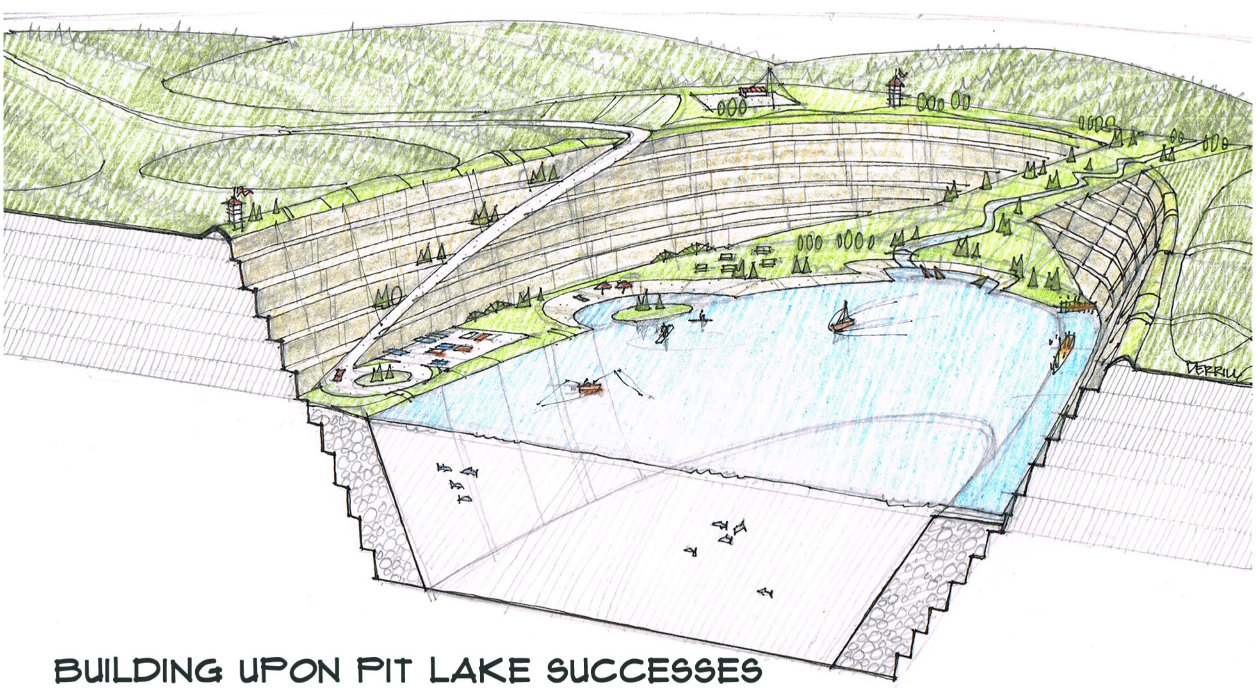
Findings	Ideal conditions for successful reclamation	General opportunity	Proposed Institute projects and activities
Mines typically defer even planned **progressive reclamation**.	Progressive reclamation is part of normal operations, land is freed up to be reclaimed every year, and areas available for reclamation are reclaimed within two years. Experience is incorporated into future plans, mines are recognized for this work, and land yet to be reclaimed at closure is minimized.	Embrace progressive reclamation practices.	Enlarge case history database / symposia to include net present value economics for progressive reclamation and effective financial assurance models for mine reclamation.
Mines often make unrealistic commitments to obtain their **initial permit**.	A DBM is used to identify the vision, goals, objectives, and design criteria and tested with engineering risk assessments — a test of reasonableness is applied. The decision-making framework is clear. The commitments are about what is to be achieved and the process for achieving it, not the exact configurations or methods.	Make only realistic commitments.	Develop how-to guidance for developing DBMs.
Inadequate **regulatory effectiveness** — there is a missing framework or clout to drive mines to achieve agreed-upon goals.	The regulatory mine reclamation mandate is simple, clear, practical, enforceable, and enforced. It needs to have some flexibility but also teeth.	Improve regulatory effectiveness.	Provide how-to guidance for improvements to regulatory effectiveness for landform design and mine reclamation. Provide guidance for regulatory policy related to mine reclamation and landform design. Develop regulatory-based case histories. Work toward establishing a global community of regulatory specialists.

Findings	Ideal conditions for successful reclamation	General opportunity	Proposed Institute projects and activities
Communities have difficulty communicating with and influencing mines. Communications typically only occur at the highest levels and are primarily a mix of "inform" with some "consult." Many lack the resources to fully participate.	Mines work collaboratively with local communities toward a shared vision and schedule for reclamation.	Provide direction for involvement and direction for local communities.	Develop how-to guidance for landform design team and local communities on collaborating within a landform design framework. Compile case histories of successful collaboration. Assist in the development and promotion of co-reclamation strategy and techniques.
Formal agreements between mining companies and Indigenous communities are common but can fall short of sufficient Indigenous engagement and input to landform design, preventing the reclaimed landforms from meet community goals and objectives.	Co-reclamation of mine sites with Indigenous communities in all aspects of governance, design, operations, reclamation, and aftercare.	Co-reclamation of mining landforms and landscapes.	
The **mine plan** is poorly linked to the reclamation plan, and most mines carry multiple competing plans.	A single mine plan, of which the reclamation plan is one lens.	Enhance mine planning.	Provide how-to guidance and education on mine planning for landform design.
Uncertainty and levels of **residual risk** preclude completion of signoff and custodial transfer.	The design basis memorandum would address residual risk up front and allow management of acceptable risks.	Manage residual risk through collaborative design, construction, reclamation, and aftercare.	Develop techniques to estimate, minimize, and manage residual risks for reclaimed landscapes. Evaluate various collaborative risk management frameworks.
Lack of sharing and permanence in **technical know-how**.	Share reclamation know-how, both internationally and at the regional scale. Knowledge is well documented and available to successive generations of miners, regulators, and communities.	Improve technical know-how.	Create a curated knowledge library website. Convene biannual case history symposia. Demonstrate the use of regional information sharing.
Opportunities for **training** in landform design and reclamation are limited, particularly for small centres or at remote mines.	Miners, regulators, and local communities have good access to training and educational materials.	Provide training and education.	Develop lectures and courses in landform design (online, in-person and university). Provide instructional videos for landform design. Facilitate a university degree in landform design.

This set of gaps, between the current conditions and the conditions for successful reclamation, may seem daunting. The Landform Design Institute was created to address such gaps, some of which are decades old. Several mines have filled all these gaps, and we can learn from such examples.

Sharing case histories will allow mines to understand and build on the successes from others. The Institute is targeting a database of at least 500 case histories and is planning a series of bi-annual case history symposia to promote sharing and awareness. The Institute recognizes that while some landform types (such as tailings facilities) are difficult and need special attention, other landform types and landform elements are more straightforward and considerable guidance is already available (for example, elements such as wetlands).

One of the bright lights in terms of landform design are pit lakes. Examples of reclaimed pit lakes that are well designed and well valued by local communities can be found around the world.[52] Successful pit lakes have a focus on post-mining land uses and water quality and there is often little to no gap between what is promised and what is delivered (although there are also examples of historical pit lakes with unacceptable water quality that remain hazardous to people and wildlife). The Institute is looking forward to building on the learnings and success of pit lake design, and arming landform design teams with the tools to improve on designs for other types of mining landforms.



BUILDING UPON PIT LAKE SUCCESSES

Benchmarks for success

The Landform Design Institute advocates for the use of landform design principles through the life of each mine and individual landform.[53] Restoring the land will become a routine and up-front component of mine planning, including governance and finance. Progressive reclamation will become standard practice, leading to a post-mining environment that provides for access to the land and continuous monitoring, maintenance, and improvement as needed. The Institute will generate practical how-to guidance at the landform and landscape scale. Achieving this vision will require large, multinational mining companies, and select individual mines, to adopt the Institute's mission while landform design knowledge is disseminated to all mines worldwide.

Building on the 2020 gap analysis, the Institute has developed a clear vision of what success looks like,[54] as encapsulated in these 10 benchmarks:

- ☐ Mines working with regulators and local communities set realistic goals and schedules for creating safe, stable, and useful reclaimed landscapes.
- ☐ Mines establish a well-designed and purposeful long-term reclamation research program[55] to test plans and address uncertainty and provide optimizations in a timely manner.
- ☐ Aggressive progressive reclamation is the rule rather than the exception. All available land is reclaimed quickly, and the amount of reclamation at the time of mine closure is minimized.
- ☐ Progressive access to reclaimed land and progressive signoff on completion of reclamation is a routine activity.
- ☐ Mines, regulators, and local communities meet all their commitments to one another, producing reclaimed landscapes all can take pride in.
- ☐ Risks are shared through equitable financial assurance systems for reclamation.
- ☐ General support exists for expanding mines and new mines, including a realistic and accepted framework and sound field performance.
- ☐ Landform design processes are adopted not only by large multinational companies, but by all mines large and small.
- ☐ A broad base of education is available to all involved in mine planning, landform design, and mine reclamation.
- ☐ The mining industry is recognized as a leader in global sustainability.

The Institute has a five-year agenda (2019–2024) in three main focus areas:

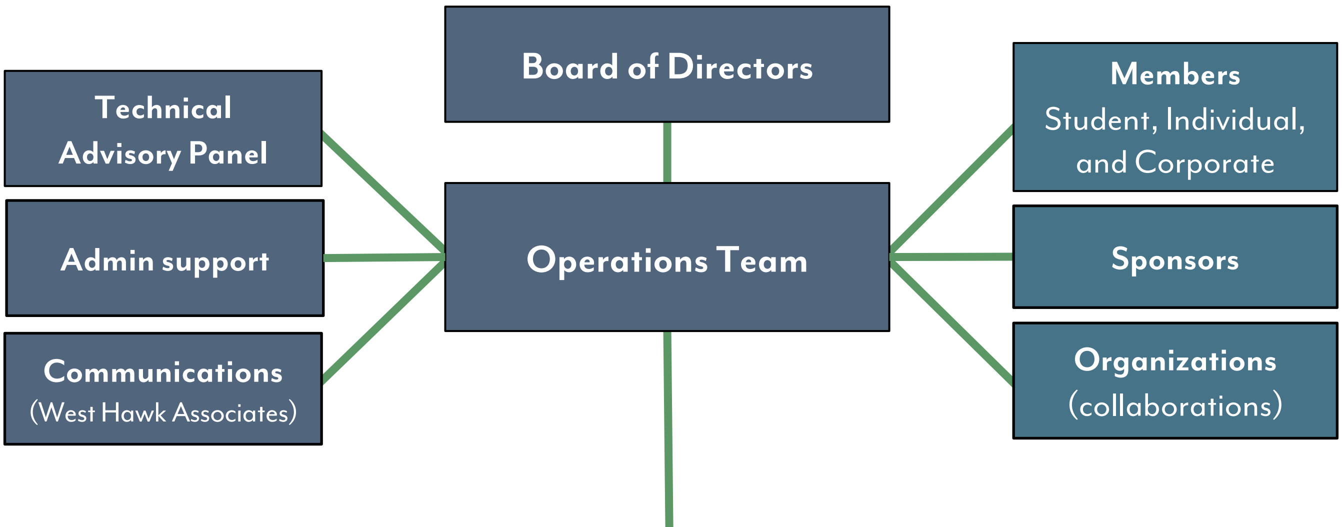
- **Developing how-to resources** important to landform design that draws on an extensive online case-history database and addresses gaps in the current technology
- **Education and training** that focuses on developing and delivering online courses, short courses and lectures, and university-based graduate-level courses
- **Supporting the global landform design community** with the above resources, but also with a full framework of landform design for mine owners, practitioners, regulators, and Indigenous and local communities, and helping them work together.

In each of the three main focus areas, the Institute is concentrating on four key themes that fulfill gaps in current landform design and closure practice as presented below:

- **Physical landform design** – design and construction of landform including topography, geotechnical, surface water quality and quantity, groundwater, ecosystems, soils, vegetation, wildlife
- **Business case and framework** – make the business and financial case and establish a business framework for mine reclamation and landform design, demonstrate how to establish governance
- **Community engagement / co-reclamation** – collaboration with Indigenous and local communities in a co-reclamation approach to reclamation
- **Socio-economic issues related to actual mine closure** – change to the local and regional economy (sudden loss of jobs, businesses, and homes) when a mine closes.

The choice and priorities of topics for our planned publications are ongoing and are based on the results of the gap analysis described above and interviews with our Technical Advisory Panel and individual and corporate members. Please contact us with ideas or proposals for topics that would aid your practice or the global community of practitioners.

LANDFORM DESIGN INSTITUTE



How-to resources	Education & training	Global landform design community support	Operations
Position papers	University guest lectures and labs (1, 2, 4 hr)	Case-history database (500 case histories)	Annual report
Technical reports, discussion papers, and literature reviews	Short courses (6, 16, and 24 hr)	Hot-topic video vignettes and short papers	Quarterly newsletter
Tools and checklists	Online course and certificate (40 hrs + assignments)	Podcast interviews	Website and social media
Conferences and journal papers	Webinars and guest speakers	Curated online library with reviews (+ imagery database)	Gap analysis
Landform design textbook	University-led grad-level courses (40 hrs + labs)	Case-history symposia	Strategic plan and business plan
Reclamation textbook	University-led degree programs	Membership directory	Membership and sponsorship outreach

Products and outreach

(Some items available publicly, some members only or at members' discount. Visit **landformdesign.com** *for details on membership.)*

How-to resources

- ☐ Position papers
- ☐ Technical reports, discussion papers, and literature reviews
- ☐ Tools and checklists
- ☐ Conferences and journal papers
- ☐ Landform design textbook
- ☐ Reclamation textbook

Education and training

- ☐ University guest lectures and labs (1, 2, 4 hr)
- ☐ Short courses (6, 16, and 24 hr)
- ☐ Online course and certificate (40 hrs and assignments)
- ☐ Webinars and guest speakers
- ☐ University-led grad-level courses (40 hrs and labs)
- ☐ University-led degree programs

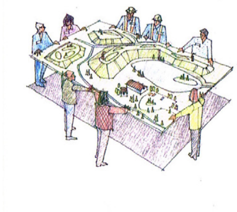
Global landform design community support

- ☐ Case-history database (500 case histories)
- ☐ Hot-topic video vignettes and short papers
- ☐ Podcast interviews
- ☐ Curated online library with reviews (and imagery database)
- ☐ Case-history symposia
- ☐ Membership directory

Operations

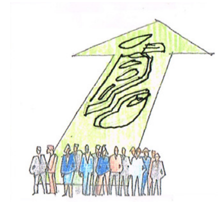
- ☐ Annual report
- ☐ Quarterly newsletter
- ☐ Website and social media

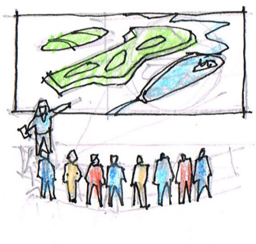
APPENDIX A:
The 12 principles of landform design



1. Mine with the end in mind. Create a shared vision for the reclaimed land among the mine, Indigenous peoples, and local communites. Work together to earn each other's trust.

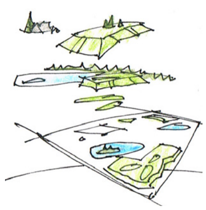
2. Establish governance. Assemble a multidisciplinary design team. Appoint a lead designer. Design mining landscapes with flair.





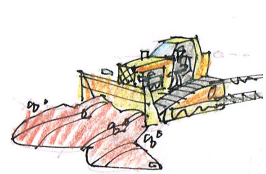
3. Set clear land-use targets, goals, design objectives, and design criteria in a Design Basis Memorandum. Support the vision. Anticipate the land will evolve over time — physically, chemically, ecologically, and socially. Design and maintain the land to adapt to these changes, including those driven by an ever-changing climate.

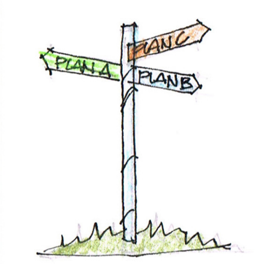
4. Work collaboratively in every endeavour. Build the reclaimed landscape with (not for) the land's users. Embrace co-reclamation.



5. Work all spatial scales — regional, landscape, landform, element — simultaneously. Temporal scales too.

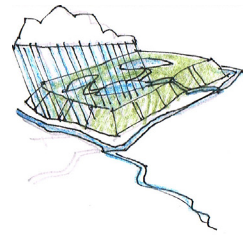
6. Design for construction and operations. Landforms and landscapes should be easy to build and reclaim using available technology that is fit for purpose. Control the source of contaminants. Avoid producing soft tailings.

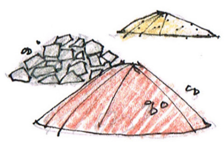




7. Use a risk-based approach. Design for the most reliable or most likely case. Embrace the observational method and true adaptive management. Enact predetermined contingencies as needed to allow the evolving land to perform as intended.

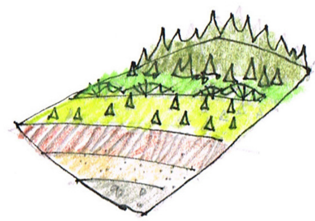
8. Follow every drop of water through the landscape. Water is both a key to life and a great agent of disruption.





9. Know your materials. Cover and revegetate all mine waste. Ensure adequate borrow. Conserve soils.

10. Favour progressive reclamation. Learn by doing and document achievements. Ensure timely access to reclaimed land. Collaborate for progressive signoff. Minimize the work required after the last tonne of ore is mined and the mill shuts down.



11. Acknowledge the land will revert to the local community and support their duty of stewardship. Reclaim every square metre. Avoid unnecessary long-term care but anticipate where it will be required. Provide full financial assurance for all phases of mine life.

12. Share experiences locally and globally. Learn from failure and celebrate success.

APPENDIX B:
Landform design glossary

This is the official glossary of landform design terms as defined by the Landform Design Institute (as of March 2021). Updates to the glossary will be posted to landformdesign.com.

Table B-1. Glossary

Term	Definition	Adapted from
Landform design		
Landform design	The integrated, multidisciplinary design and construction of mining landforms and landscapes directed by a dedicated team working with different mine operations groups and others over the life of the mine and beyond. It allows industry, regulators, and communities to work together to manage costs and risks, minimize liability, and produce progressively reclaimed landscapes with confidence and pride.	McKenna 2002
Landform	A distinctive topographic feature created by natural or artificial processes. Landforms collectively make up the surface of the earth.	
Mining landform	An artificial landform created by mining activity. It also acts as a management unit for design, construction, progressive reclamation, and signoff.	
Mining landscape	The landforms that collectively make up a mine site at a landform scale. Similar terms: mine site, lease.	Pollard 2018
Community engagement	An interactive and iterative process of deliberation among citizens with the purpose of contributing meaningfully to specific decisions in a transparent and accountable way. Engagement goes beyond dialogue to requiring true participation of all stakeholders with a role in agenda-setting and decision-making.	Swanson et al. 2011
Design team	The landform design team usually includes mine and tailings planners, a geotechnical engineer, a surface water hydrologist, a groundwater hydrologist, a geochemist, and specialists in covers and soils, vegetation, and reclamation, along with other specialists as required.	McKenna 2002 ICMM 2020
Lead designer	The team member with overall professional responsibility for the design.	ICMM 2020
Design basis	A design basis, or a design basis memorandum (DBM), to describe the expected functional intent and performance requirements of a mining landform or landscape supported by the vision, goals, objectives, and criteria.	Ansah-Sam et al. 2016
Vision	Big-picture idea of what is to be achieved, typically relating to post-mining land uses.	McKenna 2002
Goal	Overarching design or performance requirements in support of the vision.	McKenna 2002

Term	Definition	Adapted from
Objective	A design requirement in support of the goal. The objectives are site-specific and may be specific to individual mine domains, or aspects of closure. Closure objectives are derived from the overall closure vision and closure principles.	
Criteria	Specific and measurable criteria required to fulfill an aspect of the design objective. Also called design criteria or landscape performance criteria.	
Landform design scales	Landform design can be thought of as a system of nested scales: mining region, landscape, landform, landform element, microsite. See Table B-1.	Pollard 2018
Landform grading	The process of giving a slope a variety of shapes, including convex and concave forms interspersed with ridges and elbows. More broadly, it is shaping of the mining landform topography to achieve specific goals and objectives.	Schor and Gray 2007
Adaptive management	A systematic process of improving management policies and practices by learning from the outcomes of operational programs.	BCFR 2011
Landform evolution	Changes to the properties or performance of reclaimed landforms over time. These changes may occur quickly or slowly, and may be triggered by events or the results of ongoing processes. These changes may have positive or negative effects on landform performance and can occur over decades or centuries to come.	Holden et al. 2019
Cover systems	Cover systems can be simple or complex, ranging from a single layer of earthen material to several layers of different material types, including native soils, simple overburden, nonreactive tailings and / or waste rock, geosynthetic materials, and oxygen-consuming materials.	MEND 2012
Mining activities		
Closure plan – regulatory submission	A regulatory compliance document that outlines how land affected by mining activity will be rehabilitated and the associated costs. The level of detail is at the landscape / mine site scale and the plan mirrors the life-of-mine plan.	Gov WA 2015
Closure execution plan	Identifies specific actions to be carried out during the LoA in support of closure planning and implementation of closure activities.	ICMM 2019
Financial assurance	A tool that supports environmental objectives by ensuring funds will be available to guarantee effective mine closure and reclamation and avoid environmental problems.	ICMM 2006
Life of asset (LoA)	The number of years an asset (or mine) is likely to remain in service for the purpose of cost-effective revenue generation. Similar term: life of mine (LoM).	
Net present value (NPV)	The difference between the present value of cash inflows and present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of an investment or project.	

Term	Definition	Adapted from
Progressive closure	A broad term that encompasses ongoing efforts during construction and operation that advance closure activities. Examples of progressive closure activities include disturbed land rehabilitation and revegetation, decommissioning, and demolition of unused infrastructure. Similar term: progressive reclamation.	ICMM 2019
Reclamation	The return of disturbed land to a safe, stable, non-polluting / non-contaminating landform in an ecologically sustainable manner that is productive and / or self-sustaining and consistent with agreed-upon post-mining land uses. Includes rehabilitation, restoration, and remediation.	Gov WA 2015
Revegetation	Establishment of self-sustaining vegetation cover (by seeding, planting, or natural colonization) after earthworks have been completed, and in a manner consistent with post-mining land use.	Gov WA 2015 ICMM 2019
Safe	A condition in which the risk of adverse effects to people, livestock, other fauna, and the environment in general has been reduced to a level acceptable to all stakeholders.	Gov WA 2015
Stable	A condition in which the rates of change of specified parameters meet agreed-upon criteria.	Gov WA 2015
Post-mining outcomes and activities		
Abandoned mine site	Non-operational mines where mining tenure no longer exists and the responsibility for rehabilitation cannot be allocated to any individual, company, or organization responsible for mining activities. Similar terms: derelict, orphaned, former mines.	Gov WA 2015
Aftercare	Phase following temporary cessation of mining operations when infrastructure remains intact and the site continues to be managed. All mining operations are suspended, with the site being maintained and monitored. Similar term: care and maintenance.	Gov WA 2015
Completion	The goal of mine closure. The point at which a mine has reached a state at which the lease can be relinquished and responsibility accepted by the next land user. This term may also apply to an individual mining landform. Similar term: successful reclamation.	Gov WA 2015
Completion criteria	Criteria (specifications / measurements / requirements) used to measure rehabilitation success and demonstrate closure objectives have been met for each domain which consider environmental issues. Criteria may be numerical or narrative. They may have a time component and may also be linked to specific management or monitoring activities. Similar term: success criteria.	Gov WA 2015
Decommissioning	A process that begins near, or at, the cessation of mineral production and ends with removal of all unwanted infrastructure and services. Can also be applied to removal of infrastructure from an individual mining landform.	Gov WA 2015
Post-mining land use	A land use that occurs after the cessation of mining. Similar terms: land use, end land use, returning land use, targeted land use, future use.	Gov WA 2015

Term	Definition	Adapted from
Socio-economics		
Social transition	Planning, considerations, and activities undertaken throughout the LoA to shepherd the transition of a community, including its workforce, toward closure of an operation.	ICMM 2019
Indigenous and local communities	The people living near a mine site who are affected by mine operations and reclamation efforts.	
Broader community	National and international non-governmental organizations, academia, and user groups.	
Sustainability	The ability to protect the environment, contribute to the social and economic well-being of people and preserve their health in a manner that benefits present and future generations.	Gov Canada 2019
Sustainable mining	Mining that is financially viable, environmentally sound, socially responsible, implemented with sound governance, and brings lasting benefits, especially for local communities.	Strongman 2002

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Table B-2. Abbreviations

Abbreviation	Explanation
DBM	Design basis memorandum (vision, goals, objectives, etc.)
FMA	Failure modes analysis
FMEA	Failure modes and effects analysis
IFC	Issued for Construction drawings
LDI	Landform Design Institute
LoM	Life of mine (often as a life of mine plan – the mine's long-range plan)
NPV	Net present value
TAP	The Landform Design Institute's Technical Advisory Panel
TSF	Tailings storage facility

Table B-3. Mining landform types

Landform type	Description
Mined-out pit	An open-pit mine, depleted of ore, usually with semi-stable benched pit walls in bedrock and overburden.
Pit lake	An engineered water body in a post-mining pit.
Underground workings	The network of underground workings due to mining including shafts, levels, tunnels, winzes, drafts, ore passes, ramps, stopes, crosscuts, raises, declines, loadouts, portals, block caves, and glory holes.
Borrow pits	Shallow basins and mounds as remnants of gravel, sand, or clay extraction. The resulting landform is often comprised of hummocky hills with low flat wetlands.
Ore stockpiles	Temporary hills comprised of ore reserved for future mining — often low-grade or oxide ore.
Reclamation stockpiles	Temporary hills comprised of granular and organic reclamation materials.
Heap leach pile	Terraced or constant-slope, flat-topped hills built of crushed ore and treated with percolating solution applied with drip irrigation to extract metals. They have a liner with internal drains to collect the leachate.
Landfills	Various types of landfills are constructed on each lease, most of which are terraced hillslopes containing various types of wastes and byproducts (including construction wastes, municipal garbage, byproducts, and water treatment wastes). Some landfills are incorporated in the interior of other mining landforms.
Waste-rock storage facility	Overburden dumps are terraced hills created to store overburden materials. Most overburden dumps have large plateaus (which may be mounded to shed water or dished to direct surface water to a central swale) and shallow to steep slopes that often comprise a large proportion of the footprint.

Landform type	Description
Rock drains	Coarse waste-rock boulders placed to ford or cover actively flowing streams. May also be formed by segregation of waste rock during dumping.
Tailings dyke / dam	A hillslope that acts as a structure to contain tailings. Typically includes the drainage basin / pond as part of the landform. It is often terraced.
Tailings drainage basin / pond, tailings storage facility	A plateau created through hydraulic deposition of tailings sand (to form beaches) and soft tailings (untrafficable waste that is contained in the central area). For both in-pit and ex-pit tailings drainage basins, the resulting topography forms a topographic high (headwaters) in the closure landscape.
Dredge spoils	Low curvilinear hills left behind by industrial placer mining.
Plant site / mill site	Flat topographic and accessible areas that contain all the mine site facilities and associated processing facilities (ponds, tanks, etc.).
Linear infrastructure	Light-vehicle and haul roads, powerlines, pipelines, canals / diversions, ports, mine access road, exploration roads and pads, airstrip, rail lines / loadouts, drill pads.
Townsite, camp, contractor area	Mining towns and trailer camp areas used to house workers and their families, or contractor businesses.
Surface water drainage system	Drainage ditches, swales, creeks, streams, and spillways which move water through the reclaimed landscape to the external environment. Includes temporary surface water diversion systems.
Reservoirs	Ponds and lakes (and dykes) created to store or divert water, or as fish-compensation. Many were former natural lakes raised by dams. Others are lined facilities.
Sedimentation pond	A small pond used to settle solids from runoff water.
Submarine and riverine disposal areas	Tailings or waste rock placed into rivers or standing waterbodies (such as lakes or the ocean) that form large submarine fans.
Debris fans	Runoff features from mine waste dump or tailings dyke failures.
Often landform types are lumped together (e.g., underground workings and glory holes, mined-out pits and pit lakes, or sedimentation ponds and surface water drainage systems). In some cases, they may be split — dykes from the tailings plateaus they contain, waste rock dumps divided into different zones and treated as individual landforms. While using topography to define mining landforms can be helpful, designers will often choose logical management units instead.	

Table B-4. Mining landform elements[56]

Landform elements		
MINE FACILITIES (DUMP, TAILINGS, PIT) Watershed berm (bund) Ridge Mound Cover Microtopography mounds Depression / hollow Soakaway (infiltration gallery) Intermediate slope Bench Toe berm Central swale Lateral berm channel Downslope channel Outlet channel Spillway Toe ditch Fall Sedimentation pond Sludge ponds Attenuation pond Water treatment pond Outlet pond Containment berm Wetland Rock drain Diversion channel Levee Stockpile Pit wall Retaining wall Rock face / cliff Dam Dam crest Cap Upland zone Riparian zone Wetland (bog, fen, marsh, open-water wetland, swamp) Lake Inlet, outlet	Island Peninsula Shoreline Spring Heap leach pads and systems Underground workings Portal Gloryhole Ventilation raises Crown pillars PIT LAKE Inlet channel Shelf Littoral Cove Beach Groyne Riprap shoreline Breakwater Outlet channel SOILS, VEGETATION, WILDLIFE Reclamation cover Vegetation patch Brush pile Rock pile Snag / wildlife tree Nesting box Corridor Remnant stand Vegetation island Shelterbelt	DRAINAGE NETWORKS Creek Confluence Floodplain (bench) Meander Oxbow Point bar Step pool Plunge pool Riffle section Bank stabilization In-stream structure – cross, j-hook, and rock vanes Flow control structure – low head dam, weir, pier INFRASTRUCTURE Buildings – visitor centre, village, maintenance sheds, office, museum Historic workings Access roads – haul road, light vehicle road Access controls – fence, barrier rocks, gate, moat Tunnel Trail Boardwalk Laydown, pad, parking lot Boat launch, pier Bridge Culvert Ford Sign Lookout Water treatment facility Pump house Pipeline Power line Landfill Monitoring instrumentation Research plot Test pond

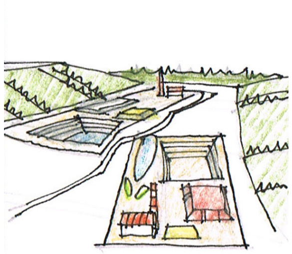
Table B-5. Levels of landform design

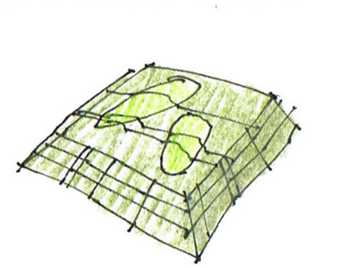
Level of design	Description
Conceptual design	The initial design. Often drawn on a whiteboard, it establishes the shape of the containment, types of materials, general stratigraphy and slope of the deposit, key elevations, and initial volumes. The team then works the next level of design on a computer. There is no specification on accuracy, but volumes of soft tailings are generally accurate to within ± 20% and capping volume to within ± 50%.
Preliminary design	Typically produced for an individual deep deposit (at the landform scale) but in conjunction with other deep deposits and the rest of the mine at the landscape scale. The design includes the selection of technologies (sometimes called concept selection), materials prescriptions, and preliminary topography and elevations. It supports development of the mine and tailings plan and the closure plan. It is typically required for environmental impact assessments, permitting, and big-picture business decisions (identification of large projects, potential risks, and costs). The same activities are involved as at other levels of designs, but with less information and some simplifying assumptions. Soft tailings volumes are typically estimated to within ± 10% and capping volume to within ± 20%. As part of the adaptive management program, the preliminary design includes contingencies in the event design criteria are not met. The monitoring program identifies these situations in time for the pre-designed contingencies to be implemented with minimal impact on ongoing tailings operations.
Planning-level design	Sometimes referred to as a feasibility design, this applies to the landform scale. The design typically includes data review, modelling and analysis, development of landform-scale design surfaces and elevations, materials, volumes, and outlet parameters. It provides information to be incorporated into various business plans (material balance, budgets, infrastructure, regulations, and risk assessments). It takes place three to five years before construction of each stage. Volume estimate ranges remain the same as in preliminary design, but more details on final design surfaces and schedule are included.
Detailed design	Involves the full landform scale, including modelling, engineering design of all surfaces for deposition and construction, schedules, material properties and volumes, and cost estimates. It elaborates on each aspect of the project, with a complete description of the design through modelling, reporting, and drawings. Detailed designs are typically stamped by the responsible professionals and guides field construction activities. They are typically done about 6 to 12 months in advance of construction of the design surface.
There are 2 additional activities of note	
Issued for construction (IFC) drawings and specifications	Communicate the final, landform-scale engineering design to the construction team.
Construction records reports	Document the constructed design for each surface to provide a basis for the design of future projects and support monitoring and maintenance. Various tools are available to track progress, deficiencies, and volumetrics.

APPENDIX C:

Five spatial scales for landform design

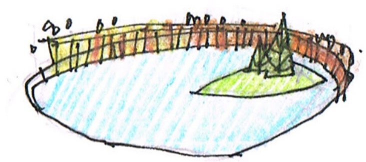
Table C-1. Five landform design spatial scales

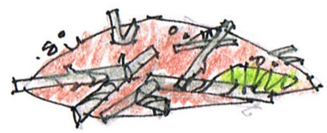




	Region	Landscape, lease, minesite	Landform
Dimensional scale	100,000 m (100 km)	10,000 m (10 km)	1000 m (1 km)
Description and examples	A grouping of mines in a valley or region	A single mine lease or property; more generally, everywhere you can see from a particular point on the land (the Renaissance definition)	A single mine facility: mined-out pit, stockpile, tailings facility, waste rock storage facility
Design effort and description	Designs by a multi-disciplinary team and revisited at a set schedule	Designs by a multi- disciplinary team which are revisited every 5 to 10 years	Facility-level design (dam design, waste rock storage design, landform design) Typically undertaken in phases. Engineering drawings and specifications
Typical regulatory activities	Policy documents, regional plans	Mine permit, life-of-mine closure plan	Specific license / approvals for mine waste structures (dams, tailings ponds)
Typical collaboration, engagement with external parties	Collaboration with regulatory and local communities	Main level of collaboration with regulatory and local communities	Fulfils closure plan expectations Opportunity to increase collaboration and engagement at this scale
Examples of typical design activities at this scale	Regional land use plan, cumulative effects assessment, surface water quality and quantity, provincial classifications (biogeoclimatic systems), regional groundwater impacts	Life of mine plan, mine closure plan, landscape ecology	Geotechnical stability, surface water drainage network, wetland placement and design, design elevations, cover designs, soil, and vegetation
Timeframes	Several hundreds of years	50 to 100 years	10 to 20 years
Typical reclamation equipment	Standard mining equipment – 100-tonne to 400-tonne mining trucks, Cat D6- to D10-sized dozers		Standard mining equipment – 100-tonne to 400-tonne mining trucks, Cat D6- to D10-sized dozers

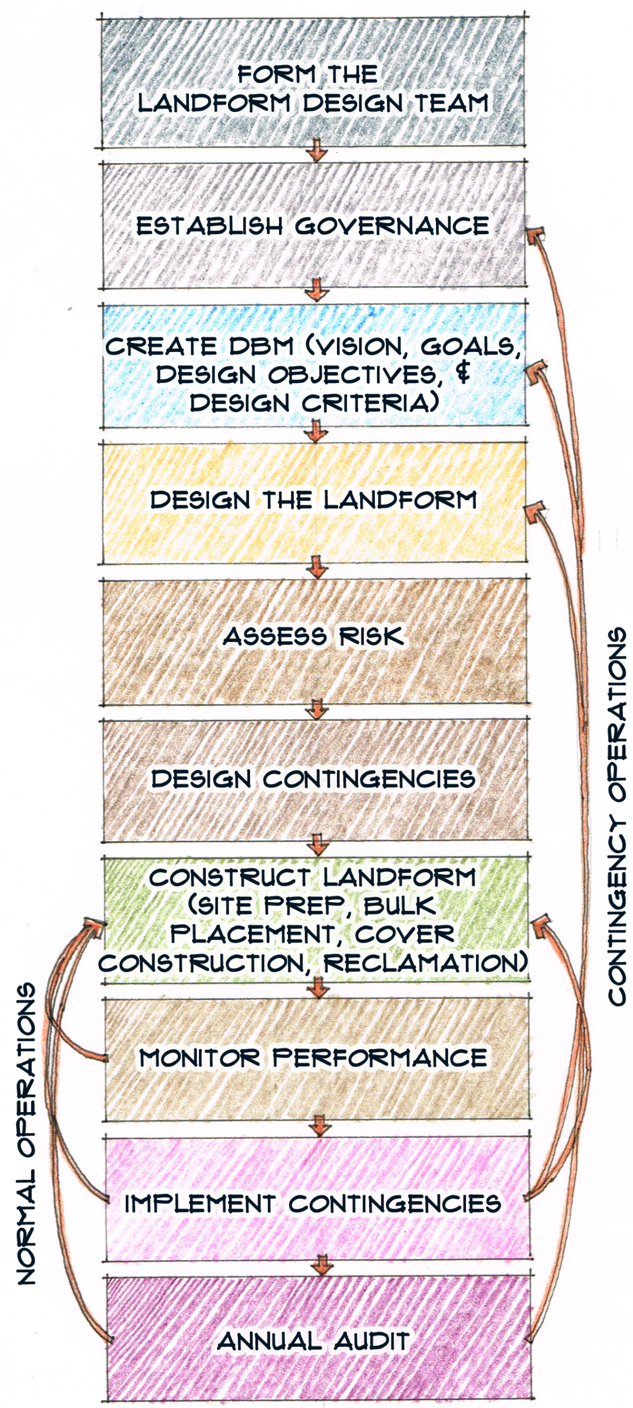
Table C-1. Five landform design spatial scales (continued)





	Element	Microsite
Dimensional scale	1 to 100 m	1 m
Description and examples	A single designed feature on a landform Toe berm, bench, shoreline, wetland	Small features typically included for specific reclamation purposes Peat mound, rock pile, or individual boulder or soil mound, brush pile
Design effort and description	Typically included as a component in a landform design or field fit as part of standard reclamation practices	Typically field fit as part of standard reclamation practices
Typical regulatory activities	Included in landform level regulation Opportunity to increase collaboration and engagement	
Typical collaboration, engagement with external parties	Fulfils closure plan expectations Opportunity to increase collaboration and engagement at this scale	
Examples of typical design activities at this scale	Smaller scale reclamation design to support a specific post-mining land use (wildlife habitat, hunting etc), aesthetics	
Timeframes	1 to 2 construction seasons	Hours
Typical reclamation equipment	Standard mining- to reclamation-scale equipment – 40-tonne truck (articulated wagons), Cat D3–D6 dozers	Smaller dozers or tracked excavators

APPENDIX D:
How to do landform design



LANDFORM DESIGN SIMPLIFIED WORKFLOW

The landform design process is listed in the accompanying flowchart. It shows a linear progression through various steps applicable to the landform or landscape (mine site) level. In reality, the process is more organic than shown, but the format allows a clear description. It is based on the geotechnical observational method[57] and has similarities to adaptive management, but is much more effective.

A **landform design team** is established – typically including six to 12 disciplines. A lead designer takes overall responsibility for the design and construction. Ideally the team is formed before mining begins, but for most mines, it will be formed partway through. At larger mine sites, there may be several landform design teams, with overlapping membership. There is typically a core team (mine planning, geotechnical, surface water, groundwater, geochemistry, soils, vegetation, and wildlife) supplemented by specialists such as limnologists or aquatic biologists for some types of landforms. The team will work for decades, often with considerable turnover.

A **governance structure** is established with corporate responsibility for the work. This may be a manager or vice-president and often mines find it useful to have a management steering committee oversee the process. Inclusion of members of Indigenous and local communities in governance is critical.

A **design basis memorandum (DBM)** is created. This is typically a 10- to 20-page document, with a nested hierarchy that includes a vision, goals, design objective, and design criteria.[58] It is quite detailed and essentially forms a contract. If there is buy-in among the mine, the regulator, and Indigenous and local communities, then meeting the design basis should be sufficient for completion and signoff. Ideally this document would be the joint product of all these groups, but in practice it is typically produced by the mine with input from the other groups. Often there is a DBM for the mine site as a whole, and a slightly more detailed one tailored for each landform. The DBM is a living document, updated as more information becomes available, as preferences change, and as more is learned. The DBM becomes a commitment of the mine and annual progress is tracked against it.

The **landform is designed** in sufficient detail to provide guidance to operations and allow robust decision-making. At the landscape scale, it is often designed to a pre-feasibility level. At the landform scale, it is often designed to a feasibility level before going to a detailed design. The landform design typically complements the mine plan / geotechnical design — the interplay between the designs is sometimes complicated. Each of the landform team members, and others in the organization, sign off on the integrated multidisciplinary design. The design is updated frequently.

Next, an **engineering risk assessment** of the design is completed. This is usually in the form of a failure modes and effects analysis (FMEA).[59] Where risks are too high, the design is modified. The team needs to recognize that the levels of acceptable risk for the mining company are often higher than that of the regulator or local communities. In some cases, an ecological risk assessment or human health risk assessment may be appropriate.

Often not all risks are mitigated. For all significant remaining (residual) risks, **contingencies are developed**. This is the heart of the geotechnical observational method and where it deviates from adaptive management. The contingencies are designed in some detail to ensure they can be quickly implemented, are affordable, will perform as intended, and will be acceptable to the mine, the regulator, and local communities. The monitoring program, discussed below, is designed to indicate when these contingencies would need to be implemented.

Next, as the mine advances, each of the **landforms is constructed**, usually four or five at any one time. As areas of these landforms are no longer needed for mining, they are resloped with dozers, the surface-water drainage is established, a cover soil is applied, and the areas are revegetated. This is progressive reclamation.

The **monitoring program** starts before mining begins and ends decades later. Results from the monitoring are used to assess whether the site is meeting the intended performance, and whether contingencies can be put in place before environmental damage occurs. Should the contingencies take a few years to construct and commission, the monitoring program and the design take this into account. The monitoring program is integral to design and is developed as part of the design process before construction begins.

Contingencies (such as adding toe berms for geotechnical stability, repairing gullies, building water treatment plants, or changes to the mine plan) are implemented if the monitoring detects unsatisfactory performance.

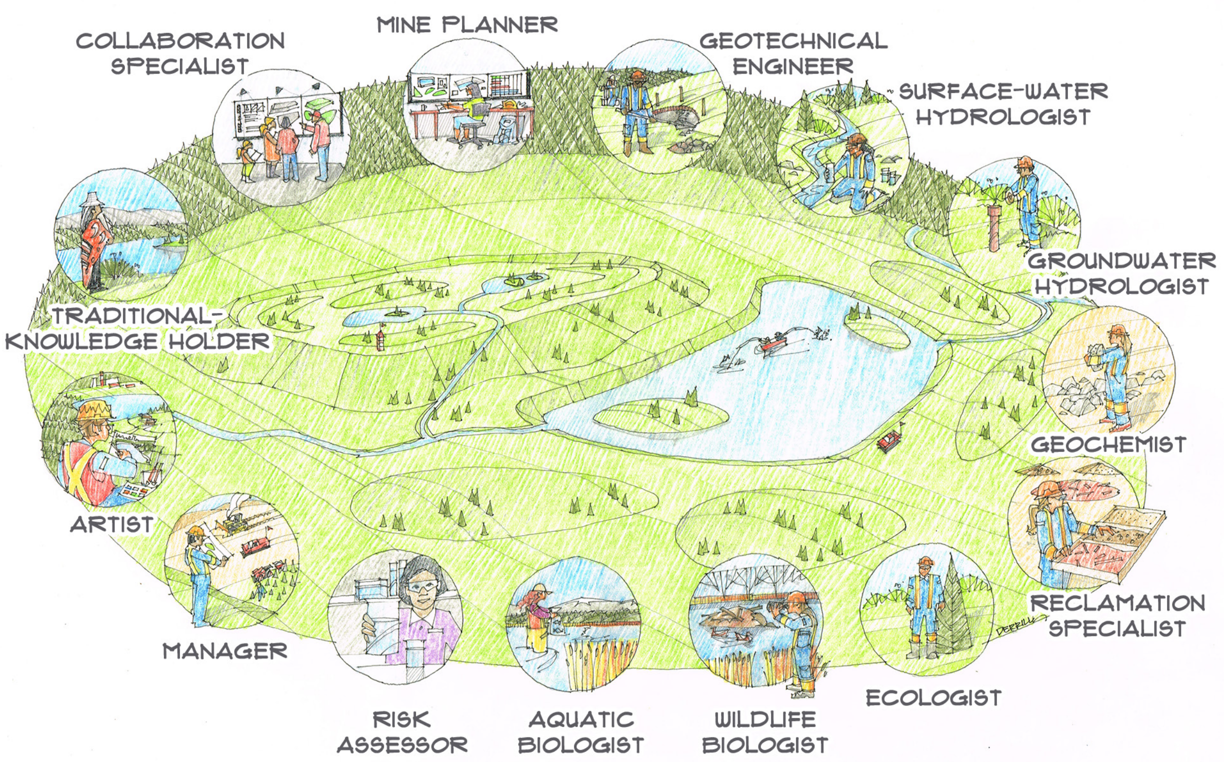
Typically there is an **annual audit** to see that the process is being followed, that all the steps are being taken, and that contingencies are being implemented if needed. This may be done by an external party. It is conceivable an independent reclamation review board might best fulfill this role.

As part of normal operations, if there are shortcomings in construction or performance, changes are made, as shown in the left-hand arrows in the above diagram. The right-hand arrows indicate the flow for contingency operations. Field operations may need to adapt, the design may need to change, the DBM may have to be updated (requiring discussions with the regulator and local communities), and if there are still concerns, it may even be necessary to reform the governance.

The changes are often augmented by field trials, including instrumented watersheds for reclamation research[60] that are designed to provide intensive monitoring data on landform design projects, particularly covers and revegetation. Intensive monitoring within the instrumented watershed is complemented by extensive but less sophisticated monitoring of similar reclaimed sites, thus allowing the mine to demonstrate acceptable performance over time and to optimize the designs and field techniques to reduce risks and costs. Often university researchers are involved in such programs.

APPENDIX E:
The landform design team

The entire landform design team is involved at **all stages**, even aftercare, but the level of effort expected of different specialists varies over time. In the early stages, the mine planner, geotechnical engineer, and surface water and groundwater hydrologists are the busiest. When it comes time for reclamation activities, the soils, vegetation, and wildlife specialists are busier.



Working in such a team is generally rewarding, but it takes several years for specialists to learn to work together, with plenty of cross-training. The level of effort in design is much higher than that for traditional reclamation, while the designs and costs are similar to (and additional to) those for dam or dump design. Some members of the team will be staff, others will be consultants. Ideally, at least one member should be a representative of the local community. An operations representative can also help keep the team grounded.

This process is overseen by lead designers, who are responsible for overall design and implementation and partially represent a counterpoint to the undesired trap of "designing by committee." They need to lead the design activities and guide the multidisciplinary team. Sometimes they will be responsible for stamping the design (providing professional responsibility) though more often the design will be stamped by a variety of specialists, each taking responsibility for well designed areas. The lead designer often (but not always) comes from geotechnical, geology, or mining disciplines.

The LDI provides courses in design and how to work in such teams, and is assembling tools and guides to aid practitioners, regulators, and local communities. It is also working on assembling a library of available information. Some of the available guidance is global, but much is highly specific to the climate and geography, and the collection of such libraries will be one of the first and ongoing tasks of the design team.

Here is a description of the roles of the team members, and the activities they tend to lead. Many of these positions are professionally regulated.

Traditional-knowledge holders are often both specialists and generalists familiar with the ecology and use of the lands around the mines. They may be on the mine staff or representatives of the local community. Some are trained in western science or engineering. Some will be elders in the local Indigenous community. Most will be stewards and users of the land.

Collaboration specialists focus on working with groups external to the mine —the regulator and local communities at larger mines often have their own group. At big mines, this is the government and regulatory affairs department, but they are often only weakly linked with the design team. They typically have the best understanding of the regulations (and how they are employed) and reporting requirements. They are often intermediaries between the mine and these other groups. They come from a variety of backgrounds, some will be social scientists, all will require training and experience in consultation. There is an opportunity for their roles in design and including others in the design team. Some will have connection to the mine's legal representatives. The need for social scientists who understand how different communities can work together is becoming apparent.

Mine planners are focused on optimizing mine waste management, putting together the initial designs of landforms, and developing sequences, schedules, and budgets. They are often mining engineers but may also be technologists or operational staff. They focus on gathering constraints and optimizing costs for bulk material placement. Some are specialists in tailings planning or reclamation planning.

Geotechnical engineers focus on the physical stability of mining landforms, specifically slope stability, trafficability, and settlement. Often they will be the engineer of record for a tailings dam or mine waste dump. Many also have geological training and some are cover-system design specialists. Much of their work is guided by sophisticated but relatively straightforward slope stability and settlement models.

Surface-water hydrologists are often civil engineers or engineering geologists by training. They focus on getting every drop of water safely off the landform and off the site, through overland flow or channels constructed on and around each landform. Some are climate specialists, some water-quality experts. They often work closely with the mine planner and geotechnical engineer to design the topography. They typically take charge in design of the site-wide drainage network. They often work with complex distributed network surface water models to calculate runoff and to design channels.

Groundwater hydrologists are typically geologists with specialized training in seepage and groundwater. Many are also geochemists by training. They tend to focus on controlling groundwater contamination, but are also closely involved in understanding water balances, water quality, and the location of the groundwater tables in mining landforms. Many are working to link surface water and groundwater models, as this is an important area for landform design – it's all the same water.

Geochemists are geologists who focus on chemical changes in mine waste, understanding how to control and manage the production of contaminants. They often have a groundwater background and many are acid rock drainage specialists. They work closely with the surface water hydrologist for water quality modelling and are often a link to water treatment specialists.

Reclamation specialists come from a variety of disciplines, often from the biological sciences or environmental management. Many are soil scientists. Their forte is the practical know-how required to organize and conduct reclamation activities, from sourcing seedlings, to setting out equipment contracts, to conducting field operations, weed management, and to reporting back to the company and regulator. Many reclamation specialists fill other technical roles on the team depending on their background and training. They are the key integrators of the various disciplines from all the sciences as well as integrators between designers and field operations.

Ecologists focus on the "living skin" of the landform — on the surficial materials and vegetation that occupy its surface. They have backgrounds in soil science and vegetation ecology, and work on the ecological, land-use, and surface-water aspects of landform design. They often play a key role in sites where creation of ecosystems and wildlife habitat are part of the land use requirements.

Wildlife biologists are involved where land uses include wildlife habitat and are usually focused on terrestrial animals and their needs.

Aquatic biologists are often more concerned with wetlands and streams and may become involved in pit lakes. Ecologists, wildlife biologists, and aquatic biologists help design and evaluate the reclaimed landscape, related to plant and wildlife performance.

Risk assessors are a new addition to the core team. Engineering risk assessment is often led by a geotechnical engineer, ecological risk assessment by a biologist or toxicologist, and human health risk assessors by the medical community. Most people are only familiar with the existence of one of these three areas, and as such, the notion of "risk assessment" means different things to different people. The identification of "residual risk" as a central hurdle to successful reclamation, and the understanding that acceptable risk is also a social and cultural issue, shows the need to develop a much more holistic use of risk assessment.

Managers are key to the team; they often act as supervisors for the staff and provide governance and supervision of the team. They focus on process, budgets, and communications.

Artists and illustrators help forge the common vision for the reclaimed landscape. They facilitate communication of details in construction, show how mining changes the land over time, communicate what the final reclaimed landscape will look like, and foster communication and dialog between all team members and all those involved. They use a variety of tools to produce drawings, paintings, 3D models, computer images, flyovers, and virtual reality products.

APPENDIX F:
Comparing conventional versus landform-design approaches

Table F-1 compares and contrasts conventional practices in mine reclamation to that of landform design based on the 2020 gap analysis interviews and discussions with other practitioners.

Observations indicate that almost all mines use a combination of conventional and landform design approaches depending on their local conditions; many mines are trying to move toward more of a landform design approach, but are limited by uncertainty. The movement toward landform design, under a variety of different names, is already underway independent of the Institute's work. One of the Institute's strategies is to support practitioners in this work. This list helps the Institute focus its efforts.

Table F-1. Comparing conventional versus landform-design approaches

Conventional approach	Landform-design approach
The business frame for mining	
No accountable executive for successful mine reclamation.	An accountable executive identified (similar to the methods used for dam safety management).[61]
Highly conceptual closure plan submitted to meet regulatory conditions.	Detailed (pre-feasibility) landscape-scale landform design and schedule fully integrated with the closure plan, useful and used for making sound decisions, plans, and supporting bankable financial assurance calculations.
Reclamation cost estimate highly unreliable — often only 5 to 10% of actual cost.	Accurate and defendable life of mine (including reclamation) cost estimates that can be relied upon by the mine, its investors, regulators, and providers of financial assurance.
Focus on minimizing cost of mine waste management, then focus on minimizing cost of reclamation.	Focus on simultaneously minimizing cost of mine waste management including reclamation.
Back-end loaded design and engineering.	Front-end loaded engineering.
Underfunded financial assurance for reclamation, only a few percent of final costs.	Opportunity for a more robust system of financial assurance such that the regulator and local community can quickly access sufficient funds for full reclamation in the event of default.
Hidden fatal flaws in design.	Use of risk assessment to identify fatal flaws and design contingencies.

Conventional approach	Landform-design approach
Team	
Team of reclamation specialists and operations people focused on regrading, placing cover soils, and revegetation (Table 2).	An integrated multidisciplinary team with a broader focus which guides each landform with a clear DBM through the process.
Poor integration with mining and tailings engineering and operations teams.	Full integration of the mining design teams with the various development and operations teams (Table 2) to address operations, mine waste management, and progressive reclamation to achieve the vision and land use goals.
Building reclaimed landscapes for local communities.	Building reclaimed landscapes with local communities as part of the landform design team.
Design basis memorandum (DBM)	
Landforms constructed with a priority on mine waste management (disposal).	Landforms constructed with a documented DBM which includes vision, goals, and objectives for the design of the reclaimed landscape.
Announce and defend initial designs, permit at any cost.	Work with regulators and local communities to jointly set realistic vision, goals, and objectives in the DBM. It is recognized that over the decades, the goals may change.
Focus on meeting permit conditions.	Focus on meeting DBM requirements where permit conditions are included.
Focus on signoff and achieving bond release.	Focus on achieving completion and signoff against DBM objectives. Working on a new paradigm, not bond release.
Undeclared service life for engineered structures and design criteria.	Declared within the DBM for each individual landform (or landform element) for example 1000 years.
Long-term monitoring is often an afterthought.	Built in to the DBM from the start, embraced as a solution and commitment.
Mine reclamation strategy – "do your best and cross your fingers."	Jointly create a design basis memorandum and get agreement on the vision, goals, and objectives and do what is required and get signoff on completion.
Meet the requirements but fail to achieve signoff due to residual risks.	As part of the DBM, forge an agreement to manage residual risks that are realistic and acceptable to all upfront.

Conventional approach	Landform-design approach
Design – Examples from various disciplines	
Bulk materials placement conducted by mine operation guided by mine planners.	Same as current practice but with additional design and oversight by the landform design team.
Mining and tailings technologies selected with irreclaimability and long-term performance as a minor component, watered down by sprawling Multiple Accounts Analysis (MAA).	More formal alternatives assessment, focus on risk of not meeting DBM requirements.
Soft tailings produced in large quantities representing liability and risk.	Soft tailings avoided, except perhaps for very small quantities that are easily stabilized, covered, and reclaimed.[62]
Dam safety design dominated by geotechnical and tailings planning considerations.	Same as current practice but supported by the landform design team.
Difficulty in delicensing tailings dams.	Delicensing is a central feature in the DBM and design.
Tailings plateau deposition at odds with watershed design – deposition does not support closure drainage.	Focus on deposition to create the required topographic surface for surface water drainage – "pour towards the outlet" or "slope to spillway." Requires the outlet location and elevation to be specified early in design.
Landform designed adjacent to linear infrastructure and lease boundaries with no provision for resloping or toe creeks.	Design provision is made for linear infrastructure, lease boundaries, resloping and closure drainage.
Surface water drainage retrofit at end of mining.	Surface water drainage and topography is an integrated part of the landform design through its design, construction, and reclamation.
The burial of soil as part of routine operations. Soil salvage (conservation) often considered cost prohibitive.	Recognizes soil is a finite resource, and seeks to generally maximize soil salvage, using direct placement where practical and soil stockpiling when needed. An accurate and conservative reclamation material balance and handling plan is central to landform design.[63] The DBM provides that soil is stockpiled as part of routine operations. Burial of soil avoided.
During pre-stripping operations, vegetation burned or buried.	Coarse woody debris used to enhance reclamation prescriptions.
Vegetation plots for reclamation research.	Instrumented watersheds (intensive and extensive) with embedded vegetation plots.
Planting of vegetation species not consistent with closure plan goals.	A clear DBM exists with a vegetation design which is acceptable to the overall vision and goals.

Conventional approach	**Landform-design approach**
Difficulty meeting closure commitments for water quality post-closure.	The DBM includes detailed design, planning, realistic predictions (based on proven concepts) and realistic costing of contingency solutions to meet commitments.
Contingency measures to address water quality from a landform with treatment which are conceptually designed.	
Infrastructure, plants, mills, airstrips, roads designed without a decommissioning plan.	Planned as part of the DBM for any design infrastructure.
Progressive reclamation	
Most of the mine site is unreclaimed at closure.	The amount of progressive reclamation is maximized and is a routine activity, ideally only a small area is left to reclaim at closure.[64]
Progressive reclamation where opportune.	Accelerated progressive reclamation to meet DBM objectives.
The reclamation team receives mining landforms and does its best to reclaim them.	Ensure there is good design throughout the lifecycle of the landform such that it is easy to reliably reclaim in the final stages with proven existing technology.
Aftercare period	
Sites abandoned in a half-reclaimed state which does not meet closure commitments.	Post-closure is a planned-for period within the landform lifecycle. The landform is fully reclaimed to an agreed-upon land use and condition (the performance of which can be assessed against the DBM).
Local communities and regulators are reluctant to accept management of an unknown landform and landscape.	Routine post-closure activities, planned at DBM stage, are managed by the engaged and informed local community.
Potential known and unknown risks remain in an unmanaged state.	Residual risks are a known entity which are actively managed.
Users banned from the land.	Progressive access to users over the life of the mine built into the DBM.
No funding for aftercare.	Full cash funding for long-term aftercare.
Lack of relinquishment which is usually the number one goal of reclamation.	The control of the reclaimed land is signed off at the DBM stage and may or may not involve relinquishment. Ideally the land is turned over to a third party for funded long-term aftercare.
Mining companies remain liable for the land forever.	Liability sharing agreed to at the DBM level.[65]

APPENDIX G:
Key references

This section is the start of a curated library of key references for practitioners. The Institute will be working to provide short reviews of each of these and other key references. Such a process will allow practitioners from different disciplines to understand the literature in all fields, and to help cut through some of the literature that is more promotional or aspirational. This will provide them with the confidence to use and quote from the best of the international literature. Please contact the Institute at **info@landformdesign.com** for personal copies of any references not available online. Members who would like to volunteer a short review (300 to 500 words) of one of these articles or one of their own favourites are encouraged to contact the Institute. Examples and a checklist for such reviews are being prepared.

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APPENDIX H:
Board and Technical Advisory Panel

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Endnotes

1. As described in this paper, mining landforms are distinct topographic features created by mining — examples include waste rock and tailings storage facilities and mined-out pits / pit lakes. Each landform becomes its own logical management unit. Together these mining landforms form mining landscapes (at the mine-site scale) connected by creeks, wetlands, and lakes — all of which are part of the surface-water drainage system. This terminology allows practitioners to tap into centuries of knowledge and publications related to natural landforms and ecological processes at these scales.
2. United Nations Department of Economic and Social Affairs. 2021. Sustainable Development. https://sdgs.un.org/goals. Accessed 2021-02-11.
3. For example, Australian Government. 2006. Mine closure and completion: leading practice sustainable development program for the mining industry. Department of Industry, Tourism and Resources. 73 pp.
4. The Institute recognizes that many practitioners work in remote mines, distant from major centres and far from universities and colleges, libraries, and conferences and course venues. It can be challenging to get approval to purchase a $100 textbook or to travel 1000 km to attend a course. The Institute's communication program will put most of the information on the internet in the form of online courses, webinars, videos, and reports / resources. Much of the information will only be available to members, but LDI membership costs will remain low. When feasible (given COVID-19), conferences and courses will be offered in person, which adds an important dimension and encourages the growth of the global community of practitioners.
5. McKenna GT. 2002. Landscape engineering and sustainable mine reclamation. PhD thesis. Department of Civil and Environmental Engineering. University of Alberta. Edmonton. 660 pp.
6. Details of the 2021 business plan are available at landformdesign.com.
7. The Institute is hopeful that some of the entries in the case history database will include unit costs, to help the industry, communities, and regulators understand, plan for, and minimize the true costs of reclamation and aftercare.
8. See AGI. 2021. *Glossary of Geology* (online edition). American Geosciences Institute. Alexandria, Virginia.
9. McKenna. 2002.
10. The conventional renaissance definition of a landscape is "everything visible from a point on the land," which is a useful concept here, too.

11. Global Tailings Review. 2020. Global Industry Standard on Tailings Management. August 2020. 40 pp. https://globaltailingsreview.org/wp-content/uploads/2020/08/global-industry-standard_EN.pdf.

12. See: OSTDC. 2014. De-Licensing of Oil Sands Tailings Dams – Technical Guidance Document. Oil Sands Tailings Dam Committee final report. Oil Sands Research and Information Network. University of Alberta. Edmonton. https://era.library.ualberta.ca/items/8131d11c-4402-4bed-b0ab-0d3833b95af6 and McKenna G and Van Zyl D. 2020. Closure and reclamation of tailings facilities using landform design. ICMM companion document.

13. Pollard J and McKenna G. 2018. Design of landform elements for mine reclamation. BC Mine Reclamation Symposium. Williams Lake. 9 pp.

14. See for example: Brown EH. 1970. Man Shapes the Earth. *The Geographical Journal* 136, no. 1 pp. 74-85; and also: Haig MJ. 1979. Ground retreat and slope evolution on regraded surface-mine dumps, Waunafon, Gwent. Earth Surface Processes. Volume 4(2): 183–189.

15. Schor H and Gray D. 1995. Landform grading and slope evolution. ASCE *Journal of Geotechnical Engineering*. Volume 121:10. Also Schor HJ and Gray DH. 2007. *Landforming: An environmental approach to hillside development, mine reclamation and watershed restoration*. John Wiley and Sons. Hoboken.

16. Sizes of mining landforms truly span orders of magnitude. From a small isolated underground mine with dry-stack tailings and a waste-rock facility less than 200 m long (< 2 hectares), to copper and oil sands mining regions, with hundreds of landforms, up to about 10 km long and with footprints of 30 km^2. Landform design principles are applied to all, but clearly the ones with city-sized landscapes (or ones with tough geochemical conditions) are that much more in need of this integrated approach.

17. Pollard J, McKenna GT, Fair J, Daly C, Wytrykush C, and Clark J. 2012. Design aspects of two fen wetlands constructed for reclamation research in the Athabasca oil sands. Mine Closure 2012 Symposium. Brisbane. Australian Centre for Geomechanics. pp. 815–829.

18. Yes, "acceptance by all" or "all groups" is a tall order and might be considered too aspirational. But if the design basis memorandum, developed collaboratively by all, can be thought of as a contract, and there is a recognized duty to sign off on completion of work well done, many of the inherent difficulties can be overcome. The Institute looks forward to compiling case histories so that all can benefit from historical experiences. True collaborative work generally results in reclaimed lands that all take pride in.

19. There is often more than one Indigenous community near the mine site and there are usually several other local communities, and it is common that different communities bring

different values and priorities to the DBM process; indeed they may all have substantially different visions for the reclaimed landscape, and these visions may differ from those of the mine and the regulator. These differences highlight the need for close collaboration from the outset to be able to construct a reclaimed landscape acceptable to all. The historical sidelining of Indigenous and local communities only means that much more work will be required to establish trust and form a working alliance; this may require a period of reconciliation.

20. Alas, this change goes against the prevailing use in modern literature. There is an opportunity for groups to champion the socio-economic issues related to actual mine closure — the massive and sudden loss of jobs, businesses, and homes when a mine closes (see for example Neil C, Tykkylainen M, ad Bradbury J. 1992. *Coping with Closure: An International Comparison of Mine Town Experiences*. Routledge. New York. 427 pp).

21. See for example: McKenna 2002 and NOAMI. 2010. The policy framework in Canada for mine closure and management of long-term liabilities: a guidance document. National Orphaned/Abandoned Mines Initiative. 140 pp. http://www.abandoned-mines.org/pdfs/PolicyFrameworkCanforMinClosureandMgmtLiabilities.pdf

22. See Anne Naeth's article in the Winter 2021 edition of *Landform Design Quarterly*.

23. Mine reclamation includes all these activities. Beyond being an excellent and concise read of a variety of topics, Vivoda and Fulcher present succinct definitions:
    - *Remediation*: The clean-up of the contaminated area to safe levels by removing or isolating contaminants.
    - *Reclamation*: The physical stabilisation of the terrain, landscaping, restoring topsoil and the return of the land to a useful purpose.
    - *Restoration*: The process of rebuilding the ecosystem that existed at the mine site before it was disturbed.
    - *Rehabilitation*: The establishment of a stable and self-sustaining ecosystem, but not necessarily the one that existed before mining began.
    - Vivoda V and Fulcher J. 2017. Remediation, Rehabilitation and Mine Closure (Series on International Best Practice, Working Paper No. 2, Mining Legislation Reform Initiative), AUA Center for Responsible Mining, American University of Armenia (Yerevan, Armenia). Retrieved from http://mlri.crm.aua.am.

24. See Pearman, G. (2009). *101 Things to Do with a Hole in the Ground*. Post-Mining Alliance. Cornwall, UK.

25. Rosenberg, Matt. 2020. How the Netherlands Reclaimed Land From the Sea. ThoughtCo, Aug. 28, 2020. http://thoughtco.com/polders-and-dikes-of-the-netherlands-1435535.

26. McKenna G, Scordo E, Shuttleworth D, Straker J, Purdy B, and Buchko J. 2011. Aesthetics for mine closure. Mine Closure 2011 Conference. Lake Louise, Canada. Australian Centre for Geomechanics. Perth. 1:603–612.

27. Peck, RB. 1969. Advantages and limitations of the observational method in applied soil mechanics, *Geotechnique*, 19, No. 1, pp. 171–187.

28. Many tailings ponds are now called tailings storage facilities (or just TSFs). Sludges and slimes are more often called fine tailings or soft tailings. Others eschew the term "tailings" entirely. To many people, the use of the term "dump" suggests an unengineered pile (although municipal landfills are highly engineered), and "waste" has negative (and perhaps legal) connotations in many regions. Waste-rock dumps therefore become "overburden storage facilities" or "rockpiles." Accurate descriptions are important, but mining literacy is also important as we deal with mining landforms from antiquity that may be hundreds or even thousands of years old.

29. A historical note: landform design started as "landscape engineering" with the publication of McKenna's thesis of the same name in 2002. And engineering can be thought of as involving 9 elements (planning, investigation, design, construction, operation, assessment, research, management, and training – each critical to landform design). But as most of the team members were not engineers, enthusiasm for the term "engineering" was lacking, and the notion of "design" was appealing. And the notion of landscape evolved on its own into landform, and hence the moniker of landform design was easily adopted by practitioners. The Institute recognizes that individual mining landforms have the best scale for design and earthworks — that for many planning activities, and certain performance activities, the landscape scale is a central focus.

30. Some think of this phase instead as all that is involved in "building the landform." While the Institute is trying to forge a common terminology, especially for its publications, it recognizes the best terms are those that work for the mine and the communities.

31. *The Society of Mining Engineering Handbook* published in 1973 provides a snapshot in time. "In a region of sparse population and arid conditions it may be acceptable to leave the mine site as is. Should a valuable natural resource, such as water, exist in this same area, it may be desirable to grade unconsolidated material to a stable contour to prevent water pollution. At the other extreme, where the site under arid conditions is near an area of high population density, complete backfilling may be desirable."

32. For example:
    - United States Department of the Interior. 1967. Surface mining and our environment: a special report to the nation. United States Department of the Interior, Washington, 124 pp.

- SME. 1973. Mining Engineering Handbook. Society of Mining Engineers (AIME). New York. 2 vols.

33. INAP. 2017. Global Cover System Design: Technical Guidance Document. International Network for Acid Prevention. 126 pp.

34. INAP. 2018. GARD Guide. Global Acid Rock Drainage Guide. International Network for Acid Prevention. http://www.gardguide.com

35. See:
    - Government of Western Australia 2020. Mine Closure Plan Guidance – How to prepare in accordance with Part 1 of the Statutory Guidelines for Mine Closure Plans. Department of Mines, Industry Regulation, and Safety. Version 3. 74 pp. http://www.dmp.wa.gov.au/Documents/Environment/REC-EC-112D.pdf
    - IBRAM. 2014. Guide for Mine Closure Planning. Instituto Brasileiro de Mineracao. Brasilia: Brazilian Mining Association. 225 pp.
    - ICMM. 2019. Integrated Mine Closure: Good Practice Guide. Second edition. London: International Council on Mining & Metals.
    - APEC. 2018. Mine closure checklist for governments. Asia-Pacific Economic Cooperation. APEC Mining Task Force. Singapore. February 2018.
    - Australian Government. 2006. Mine closure and completion: leading practice sustainable development program for the mining industry. Department of Industry, Tourism and Resources. 73 pp.

36. Decipher. 2020. Mine closures an industry challenge. *Business News* (Sponsored Content). July 30, 2020. https://www.businessnews.com.au/article/Mine-closures-an-industry-challenge. Downloaded Jan 3, 2021. Businessnews.com. Perth, Australia. 3 pp.

37. The Landform Design Institute is looking forward to cataloging and examining the mining regions in the world to understand how climate, geology (and the geology of the orebody), and regulatory environment impact design. The LDI will identify the commonalities, the differences, and what can be learned from these regions.

38. See:
    - Holden A, Provost H, Pollard J, McKenna G, and Wells PS. 2019. Evolution of landforms in reclaimed landscapes in the surface mineable Athabasca oil sands. Tailings and Mine Waste Conference. Nov 17-20. Vancouver. 16pp.
    - McKenna. 2002.

39. It is not clear that the current paradigm of transferring custodianship of reclaimed land (while retaining liability for the residual risks) is the best path for most sites. Good governance indicates those who own the risk should ultimately manage the site. But as recognized in the

Principles of Landform Design (Appendix A), it is recognized that companies typically only last decades or at most a few hundred years, and that responsibility of the land will revert back to the state and local communities. Recognizing this, there is a duty of the state and local communities to ensure an orderly and funded transition.

40. Risk assessment means different things to different people, and many don't understand how the term is used outside their field. For example, engineers think of risk assessments in terms of physical failure modes, event trees, a red-yellow-green corporate risk acceptance matrix, and residual risk. Biologists often think of ecological risk assessments with a focus on toxicology of substances released to the environment. Human health risk assessment looks at the probability and nature of adverse health effects in humans exposed to contaminants now or in the future. All of these relate to landform design, and practitioners need to become conversant in each.

41. From INAP. 2017.

42. When we give landform design courses, we include an exercise in which we divide up participants into several landform design teams of four or five participants each. We give them the same initial design for a mining landform and assign each group a different land use that covers a broad spectrum. We are constantly amazed and delighted by the different designs and the different solutions for landform design based on meeting the required land uses. Land use is close on the heals of climatic regime as an overarching design factor. Also, see the wonderful cartoon in Vandenberg JA and McCullough CD. 2018. Key issues in mine closure planning for pit lakes. Book chapter. Spoil to soil – mine site rehabilitation and revegetation. CRC Press. Taylor & Francis Group. Boca Raton. pp. 175-188.

43. See:
- INAP. 2017.
- Slingerland NM. 2019. Geomorphic landform design and long-term assessment of tailings storage facilities in the Athabasca oil sands. PhD thesis in Geo-environmental Engineering, Department of Civil and Environmental Engineering, University of Alberta. Edmonton. 341 pp.

44. Daly C. 2019. A New Approach: Indigenous Co-Led Landscape Reclamation in the oil sands. Third Annual Environmental Design Research Conference. Calgary.

45. Stella Swanson of Swanson Environmental in Canada (personal communication) notes that "Just having natural scientists and engineers around the table will not be sufficient when it comes to truly weaving Indigenous knowledge into landform design." See also Jimmy E and Andreotti V. 2019. Towards Braiding. Musagetes. Guelph, Ontario. eBook. 104 pp. https://musagetes.ca/wp-content/uploads/2019/07/Braiding_ReaderWeb.pdf

46. There is but one plan, no separate "closure plan." The mine plan, the tailings plan, the wetland plan, the reclamation plan, the closure plan, the business plan, the plan submitted to the regulator, the 10 year plan, the life of mine plan, the short term mine plan — these are all just different components of the one plan.

47. To achieve this in practice, pre-production exploration activities would have to be increased dramatically at most mines, which would result in greatly increased up-front cost. What is desirable is some additional exploration aimed at reducing uncertainty — many mines postpone reclamation as they "look for the other half of the orebody" in the years before mine closure. Clearly there is an opportunity for risk reduction.

48. Regions have an intrinsic drainage density for natural lands, and many kilometres of streams per square kilometre of land, a function of climate and geology. Nature will imprint a similar drainage density on reclaimed landscapes and designers can anticipate the density and build it into design, with ephemeral creeks coming off landforms, joining toe creeks at the base of landforms, and collector creeks carrying this water safely offsite. If this surface water drainage density is 1 linear kilometre of stream for every square kilometre of mine reclamation, then many sites will require many kilometres of streams to be constructed; some mines will require hundreds of kilometres of streams, some mining regions will require thousands of kilometres of streams. Costs of this oft-overlooked aspect of mine reclamation can be optimized in the landform design, and especially by mining with the end in mind.

49. Syncrude. 2004. Discovering Nature's Way: Instrumented Watersheds for Reclamation Research. Syncrude Canada Ltd. Fort McMurray, Canada. 40 pp.

50. Supporting the goals and objectives that are SMART: specific, measurable, achievable, relevant, time-oriented, agreed by the mine, regulator, Indigenous and local communities.

51. McKenna. 2002.

52. See:
    - McCullough CD, Schultze M, Vandenberg J. 2020. Realizing Beneficial End Uses from Abandoned Pit Lakes. Minerals 10:133. https://doi.org/10.3390/min10020133
    - McCullough CD. 2011. Mine Pit Lakes: Closure and Management. Australian Centre for Geomechanics. 182 pp. https://acg.uwa.edu.au/shop/plakes
    - Castendyk DN, Eary LE. 2009 (eds). 2009. Mine pit lakes: characteristics, predictive modeling, and sustainability. Society for Mining, Metallurgy & Exploration. Littleton, Colorado.
    - CEMA. 2014. Guidelines for Wetlands Establishment on Reclaimed Oil Sands Leases. Cumulative Environmental Management Association. 494 pp.

53. More information on the Institute, its strategic plan, and its five-year plan are available at landformdesign.com

54. These benchmarks will feed into the Institute's 2025 and 2030 assessments regarding the efficacity of the progress toward our mission.

55. The topic of an upcoming Landform Design Institute Technical Report. In the meantime, there are many references on this topic including McKenna G, O'Kane M, and Qualizza C. 2011. Tools for bringing mine reclamation research to commercial implementation. Tailings and Mine Waste 2011 Conference. Vancouver. Nov 6-9. 11 pp.

56. Table adapted from Pollard J and McKenna G. 2018. Design of landform elements for mine reclamation. BC Mine Reclamation Symposium. Williams Lake. 9 pp.

57. Peck RB. 1969. Advantages and Limitation of the Observation Method in Applied Soil Mechanics. Geotechnique. Volume 19 (2). pp. 171–187.

58. Ansah-Sam M, Hachey L, McKenna G, and Mooder B. 2016. The DBM approach for setting engineering design criteria for an oil sands mine closure plan. Fifth International Oil Sands Tailings Conference, December 4–7. Lake Louise, Alberta. University of Alberta Geotechnical Group, Edmonton. 11 pp.

59. See MEND. 2012. Cold Regions Cover System Design Technical Guidance Document. MEND Report 1.61.5c. Consultant's report prepared by Okane Consultants for Mine Environment Neutral Drainage Program. July 2012. 177 pp.

60. McKenna G, O'Kane M, and Qualizza C. 2011. Tools for bringing mine reclamation research to commercial implementation. Tailings and Mine Waste 2011 Conference. Vancouver. Nov 6–9. 11 pp.

61. Just who this executive is accountable to is an important area to explore. One might assume that if there is a governance team that includes representatives from the mine, Indigenous and local community representatives, and the regulator, that accountable executive would be responsible to this group, and those responsibilities clearly defined. The parallels with such a role with respect to dam safety are being explored by the international mine / tailings community presently.

62. Jakubick AT and McKenna GT. 2001. Stabilization of soft tailings: Practice and experience. Eighth International Conference on Radioactive Waste Management and Environmental Management (ICEM '01). Brugge, Belgium. American Society of Mechanical Engineers.

63. The Institute is planning a technical report that provides the "how-to" guidance for managing reclamation material and preparing a reclamation material balance.

64. For a large coal strip mine, only a few percent of the land may be disturbed. Some strip mines have only a four year gap between initial stripping of vegetation and final reclamation of the "strip." One Australian bauxite mine completes reclamation of each small pit within a year. Large deep open pit mines with a single large tailings pond struggle to have more than 20% reclaimed at closure. There is ample room for research to help most mines accelerate progressive reclamation.

65. Examples of liability might include poor ecological performance, a previously undetected groundwater contamination plume, a major geotechnical slope failure or slumping, or failure to meet environmental permit conditions.

The **Landform Design Institute** is dedicated to creating and supporting a community of landform design practitioners. Its intention is to help their teams design and build truly sustainable mining landscapes.

Our mission: to make landform design routine in the mining industry worldwide by 2030 by developing "how-to" resources, providing education and training, and supporting the global landform design community.

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