

DEVELOPMENT OF A GLOBAL COVER SYSTEM DESIGN TECHNICAL GUIDANCE DOCUMENT

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ABSTRACT

The International Network for Acid Prevention (INAP) is an organization of international mining companies dedicated to reducing liabilities associated with sulphide mine materials. Liabilities associated with mine closure span the globe, occurring across a climate, hydrogeological and material spectrum. Cover systems are a practical tool in managing closure liability surrounding reactive wastes, and thus are required to perform under a gamut of site specific conditions. Previous guidance specifically addressed cover system design as it pertains to cold regions but to date, no further material exists as it specifically pertains to cover system design on a global scale. This paper describes the technical guidance approach for cover systems globally being developed by O’Kane Consultants Inc. (OKC) with the assistance of a Technical Advisory Group (TAG), funded through INAP. The focus is a conceptual filter framework philosophy used to rapidly refine cover system alternatives through a set of site specific filters, to more efficiently determine cover systems for further evaluation. Site specific filters employ the Köppen–Geiger climate classification system to incorporate seasonality into design. A process based approach is used through each refinement to better understand mechanisms and controls that can be exploited, enhanced and combined to achieve reductions in acidity generation and transport. The management of oxygen and net percolation based on each site specific filter is discussed in detail along with timing of reclamation and performance value. Evaluation of cover system performance and risk is not possible or complete without discussion of performance assessment period and design life. Existing guidance have briefly covered landform design, whereas this document highlights the importance of developing covers and landforms in concert. Furthermore, this guide advances cover system design of integrating the mine waste landform into the site wide water management strategy. The document’s second focus surrounds generic case studies and real case studies to further demonstrate the utility of the proposed framework.

KEY WORDS

Cover systems, design framework, landform integration, mine reclamation.

INTRODUCTION

Performance expectations of mine waste management plans, mined waste landforms, and their associated cover systems are high. The key issue is management of chemically reactive mine waste, which is typically associated with sulfide oxidation, and the concomitant release of constituents of concern. Effluent from sulphidic mine waste during operations and closure can report as basal seepage, groundwater toe seepage or drainage from mine openings or pit walls, which can impact both surface water and groundwater. This process is referred to as metal leaching (ML) and acid rock drainage (ARD), or ML/ARD. The result is often seepage from reactive mine waste with elevated sulfate salinity and/or acidity and dissolved metals.

The guidance document presented builds upon previous work completed in the Global Acid Rock Drainage Guide (INAP, 2009) on cover system design, construction, and performance monitoring. This guidance seeks to further subdivide the applicability of each cover system strategy on a site by site basis by recognizing a continuum of cover system function exists for managing net percolation (NP) oxygen ingress (O₂) and erosion potential.

The first half of the guidance document includes a holistic framework for management of reactive/ non-reactive materials during operations and at closure. The framework for cover system design is presented at a high level, suitable for readers with a minimal technical background. The framework is presented to form a conceptual basis using a hierarchy of, climate, materials / geology, and topography, allowing the formation of a conceptual model to understand the tendencies for water movement on a site specific landscape. Ultimately, climate, materials /geology, and topography will govern how cover systems perform, and it is up to cover system designers to manipulate these components to achieve desired performance. Application of the conceptual framework presented is not entirely attainable at the current time; however, the advocates that it is the direction the industry should be headed to better resolve problems facing them. Stakeholders and mine planners are able to use the framework to evaluate cover system design proposals in a hierarchical fashion to ensure important design concepts have been considered.

Appendices will be referenced in the main body of the guidance document, and require readers to have a better understanding of water migration in soils, in particular unsaturated soils, in addition to mass transfer knowledge. Information presented in the technical appendices represents the best state of knowledge available as of the preparation of this guidance document and targeted for cover system design practitioners. The technical material is largely excluded from the body text into appendices so it can be updated as new science and state of understanding evolves pertaining to cover systems, becoming a living document.

OVERVIEW OF GENERIC COVER DESIGN APPROACH

The formation of ML/AMD is most generally controlled through limiting water flux into reactive mine wastes and gas flux, primarily oxygen to reactive mine wastes. It is important to recognize that each site will be able to manage NP, O₂ and erosion to a certain extent based on climate, hydrogeology, and materials, as well as the type of cover system employed. The two most common purposes for utilizing a cover system include management of oxygen and water to the underlying reactive materials. Additionally, cover systems must also be a component of developing a stable landform in the context of managing erosion (i.e. geomorphic stability). A continuum of cover system functionality is discussed for these three aspects (i.e. net percolation, oxygen ingress, and erosion), and is presented conceptually within Figure 1 in terms “very low”, “low”, “moderate” and “high” NP, O₂, and erosion rates.

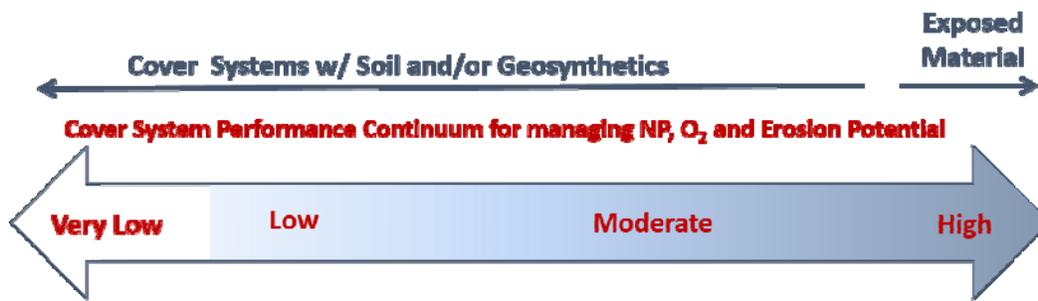


Figure 1 Qualitative cover system functionality continuum.

Continuum of NP Control

Generally, covers have been thought to limit NP into waste is by one of two methods:

- 1) **Diversion** – a layer of the cover system may be constructed from materials with a sufficiently low hydraulic conductivity so as to limit downward percolation of rainfall or snowmelt and ‘release’ water as surface runoff and/or interflow.
- 2) **Store-and-release** – infiltrating water is stored within the rooting zone of the cover system so that it can be subsequently released via evapotranspiration (ET). In these types of covers, the objective is to minimize net percolation by returning most of the infiltrating waters from storage to the atmosphere via ET.

To achieve 100% of the function for each one of the end members is practical. Rather, a continuum exists, which is a function of climate, hydrogeology, materials and vegetation. It is important to understand that all cover systems provide store and release components as well as diversion functionality under a specific set of conditions. Therefore, cover systems functionality occurs as part of a continuum with a focus on a store and release end member focusing on enhancing storage and ET components of the water balance and a diversion end member relying on runoff and interflow being dominant components of the water balance (Figure 2). Because cover systems exist as a point on a functionality continuum, Store-and-release covers

still possess water-shedding abilities when infiltration excess runoff occurs during high intensity precipitation events. Likewise, cover systems with a focus on water diversion, often possess vegetation or small amounts of storage that contribute to evapotranspiration. Therefore, in using climate as a primary filter to refine cover system design alternatives, one can identify on a site-specific basis the dominant mechanisms of the water and energy balances to be enhanced and used in conjunction with subsequent filters (i.e. materials) to best achieve the required performance.

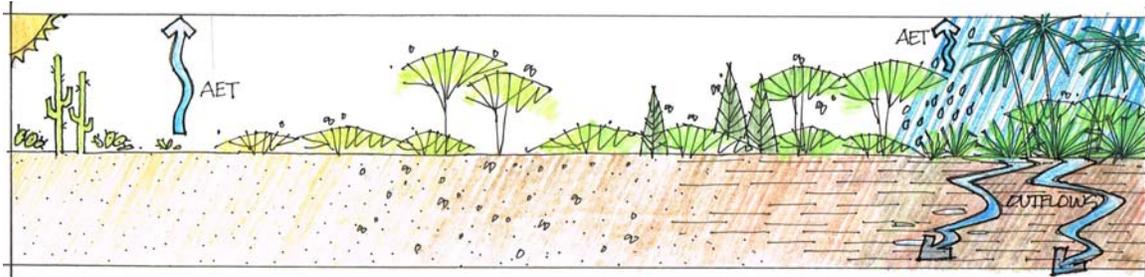


Figure 2 Cover system function continuum for managing NP with dominant water balance components identified based on climate (arid sites from left, to temperate center, and tropical far right of the continuum).

Continuum of Oxygen Ingress Control

Alternatively, or if managing net percolation is also feasible through the use of an engineered cover system design, limiting the flux of oxygen to underlying waste presents another control mechanism for managing production of ML/AMD. Management of gas flux requires addressing diffusion and advection gas fluxes. Therefore, understanding the physical controls on each one of the mechanisms is a key in cover system design.

Control of gas flux resulting from diffusion is done through managing the diffusion coefficient of waste or cover system material. Diffusion coefficients can be decreased through the use of finer textured material, or by decreasing the air filled porosity of the material by increasing water contents. Using this control mechanism often requires near saturated conditions be maintained throughout the year, spanning all seasons (Figure 3). Figure 3 represents a generalized understanding of O_2 control mechanisms based in particular due to soil water conditions to control advection. Further refinement using material filters will identify if controls can be implemented. If there are seasons where evaporation grossly outweighs precipitation, sufficient storage capacity is an engineering requirement that needs to balance water requirements for plants and maintaining cover system saturation. Alternatively, diffusive flux can be controlled by decreasing the diffusion gradient by altering path length or concentration differences. Altering the path length will be largely managed through geometrical constraints of landforms, while controlling differences in concentration will largely depend on internal waste geochemistry as atmospheric concentrations remain static.

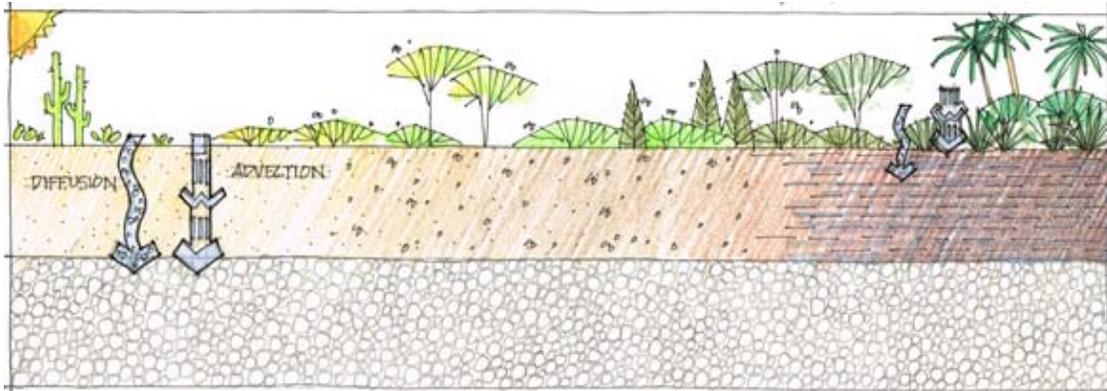


Figure 3 Cover system function continuum for managing O_2 with dominant gas transport mechanisms generally identified based on climate. Arid sites from left to temperate center and tropical far right of continuum.

Continuum of Erosion Control

Conceptually, like NP and O_2 , erosion potential occurs as part of a cover system continuum of functionality. Generally, cover system erosion potential is controlled by preventing raindrop erosion and slow surface water velocity in bare areas. This can be achieved by managing: material texture, slope length, slope angle, and vegetation; that will affect erosion simultaneously on cover systems, producing a unique potential erosion risk. Erosion management should aim to achieve the same erosion potential across the entire landform. Due to differences in water balance, energy regime and topography across a landform, multiple strategies may need to be employed to achieve equal erosion rates.

Immediately following construction, or if rapid establishment of vegetation is difficult (i.e. cold climates) more emphasis on material selection and landform design becomes important. A reliance on vegetation can be used to provide long term erosion protection, other aspects of the cover system design must be manipulated to create a stable landform with acceptable mass loss. Erosion potential generally increases with greater slope length or angle, coarser textured material and decreasing vegetation cover. Therefore, by manipulating these parameters in cover system design, cover systems can be constructed with increased physical stability even in the absence of vegetation.

General Cover System Design Alternatives

In order to meet the chemical, physical and land-use objectives described in Section 2, various cover system designs may be employed. Cover system design alternatives are described early in the document at a high level to provide context for future chapters. For the purposes of describing the appropriate cover systems, the designs have been divided into the following six categories: erosion -protection cover systems, store-and-release cover systems, enhanced store-and-release cover systems, barrier-type cover systems, and saturated soil or rock cover systems.

FILTER FRAMEWORK FOR COVER SYSTEM DESIGN

This guidance utilizes a filter framework for addressing cover system design globally. The premise is based on a filter set used to inform cover system design. Filters, as defined for this framework represent an attribute of the site (climate, hydrogeology, materials, etc.) that further constrain design alternatives to achieve the desired performance (Figure 4).

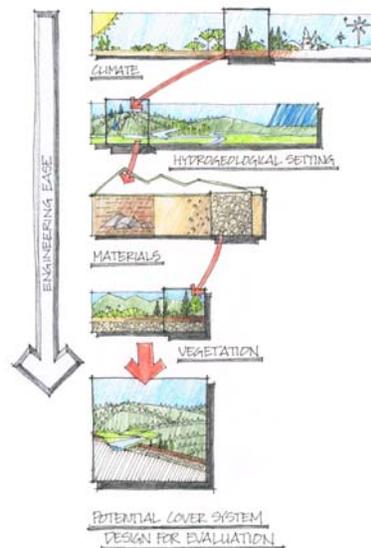


Figure 4 Filter framework for cover system design. Climate represent filter with largest impact on cover system design, while also representing a site attribute not easily modified through engineering design compared to vegetation.

Before any information is provided regarding climate, unlimited cover system design alternatives exist. As soon as climate is specified and seasonality is understood, particular designs may no longer be capable of meeting performance criteria. For example, Figure 5 below demonstrates that on a conceptual basis, tropical sites typified by large magnitude precipitation events, will have a more difficult time in managing NP as compared to an arid regions with similar cover design.

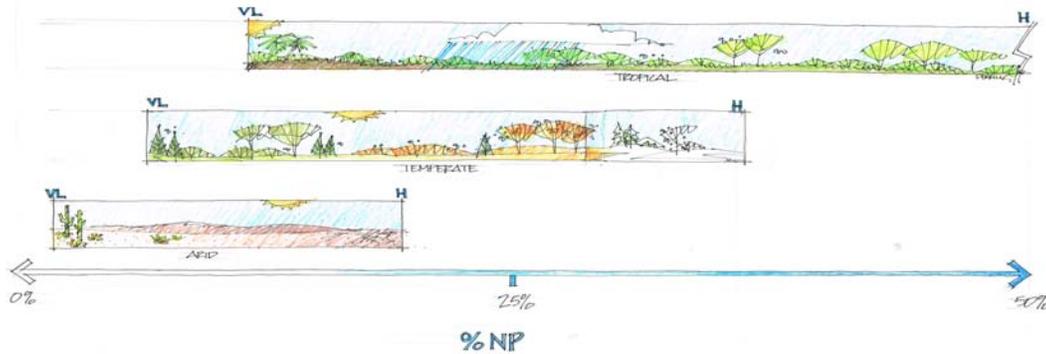


Figure 5 Conceptual net percolation management based solely climate generalizations of the Köppen classification system.

The broadest filter is used to refine gross climatic understanding. With regions of the world divided according to the Köppen-Geiger classification system (Peel et al., 2007), one is able to express the seasonal and annual tendencies of a region based on precipitation inputs and temperature. Precipitation and temperature are integral parameters in understanding the physical processes which govern gas and water transport within mine waste material and geochemical reaction rates. Although covers systems represent a continuum of functionality, the climate filter allows the designer to rapidly refine conceptual designs and identify dominant physical processes that can be exploited and/or enhanced to achieve performance criteria. This first filter also represents an aspect that cannot be modified through engineering efforts, or at least to any significant affect; therefore, the filter forms the base of the conceptual design.

CLIMATE CLASSIFICATION

Major climate regions were selected based on the occurrence of past, current and future exploration efforts as indicated with the Map Mine Mapper tool (InfoMine, 2013). Composite maps were used to overlay point data of mining activity with each major climate type (Figure 6). Although not all climate regions possess wide spread mining activity, each climate type serves to capture major concentrations of mining. Although the location of mining operations is determined by geology, it is evident that although the majority of mining in the world is generally concentrated based largely on geology, mining activity is wide spread, spanning a full spectrum of climates. Thus, the framework must include cover system guidance applicable to all climate types, using climate type to quickly focus suitable cover system alternatives.

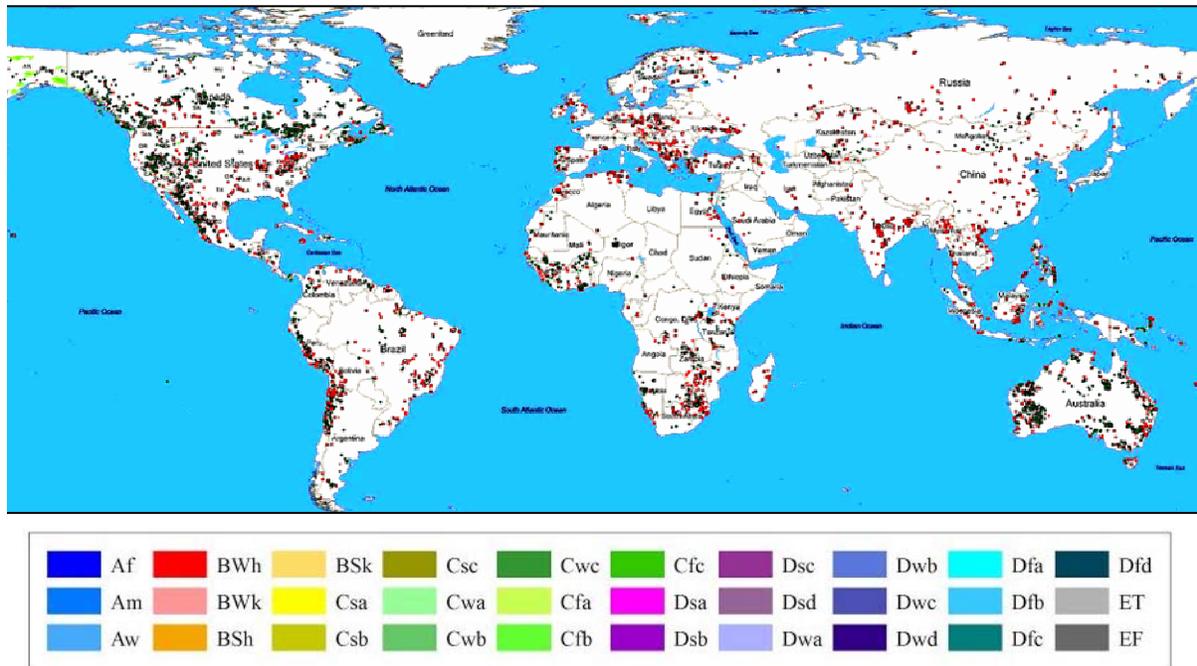


Figure 6 Major regions focused in the guidance will include all climates. Existing mines (red dots) and proposed future mining (green dots) occur throughout the climate spectrum.

Regions of the world are divided based on a large global data set of long-term monthly precipitation and temperature station time series. These climatic thresholds were developed in part due to field observations using landscape signals such as vegetation. Due to its strong ties to landscape signals such as vegetation and related soil development, the Köppen system is attractive for the framework put forth in this guidance document, which includes filters for climate, materials and vegetation. By combining the major climate region with each sub classification based on PPT and temperature seasonality, a more refined site-specific picture exists compared to conventional annual averages where many critical elements are lost or hidden in the average

The climate classification system then allows designers to quickly assess climatic inputs and the major elements that can be exploited and used for cover systems depending on the climatic setting. For each sub classification, the guidance aims to highlight cover system components to be enhanced, exploited or combined to achieve performance, without further setting, material and vegetation inputs.

Although climate represents the broadest filter and most largely refines design, other filters exist and require site-specific data to further focus design alternatives. Climate variability, climate change and climate controls on NP, O₂ and erosion is discussed in greater detail within the document. Following climate, the next filter for cover system alternative refinement is for materials which includes general discussion on availability of cover system materials, characterization and material evolution. More technical information is provided in appendices as to allow the conceptual framework from being lost in technical detail. Furthermore, micro-climate attributes resulting from topography are explored as potential tools to alter landform water and energy balances

ACID PRODUCTION

ML/ARD is usually a critical aspect within mine closure plans, including the design of cover systems. Demonstrating the benefits, or rather the magnitude of benefits, provided by cover systems to prevent/mitigate adverse impacts to receiving environments including the implications for water management (quantity and quality) and water collection/treatment systems is often challenging.

For this guidance, the key geochemical to be addressed is the oxidation of sulphidic material, recognizing that many other geochemical issues may be present on a specific site. Identifying if / what geochemical problems exist for a specific site should be a critical first step in the cover system design process such as outlined in the GARD Guide. Identifying the geochemical processes will highlight mechanisms the cover system design should seek to control. In most situations, the chemical loading principals and conceptual models presented may still be largely applicable. For other reactive materials, oxidation is a major issue as is managing NP to prevent mobilization. NP usually leads to the flushing of first pore volumes, in which the majority of COCs will be presented. Therefore, identifying the geochemical problem is a critical first step in understanding how it can be managed.

Two Conceptual Models for Acidity Generation

The guidance document discusses two competing models for acidity generation from a theoretical standpoint. The first assumes acidity load increases linearly with increasing NP, while the second model assumes acidity load remains constant with changes in NP. Practically, the acidity load must be zero when the NP rate is zero for model 2 and inherently assumes that there is a 'jump' to a high acidity load with very little net percolation.

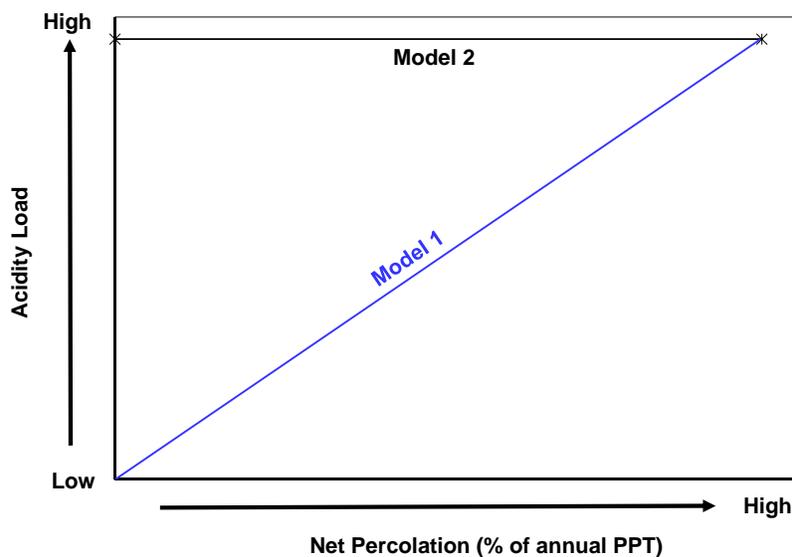


Figure 7 Conventional conceptual models showing relationships between acidity load and NP.

Given that: Acidity Load = [Solute Concentration] x Flow (i.e. NP), Model 1 results in constant ML/ARD solute concentration, and independent of NP (Concentration 1 in Figure 7). Model 2 assumes very low NP will result in very high acidity concentration, while high values of NP, will contribute to very low acidity concentrations due to dilution (Concentration 2 in Figure 7).

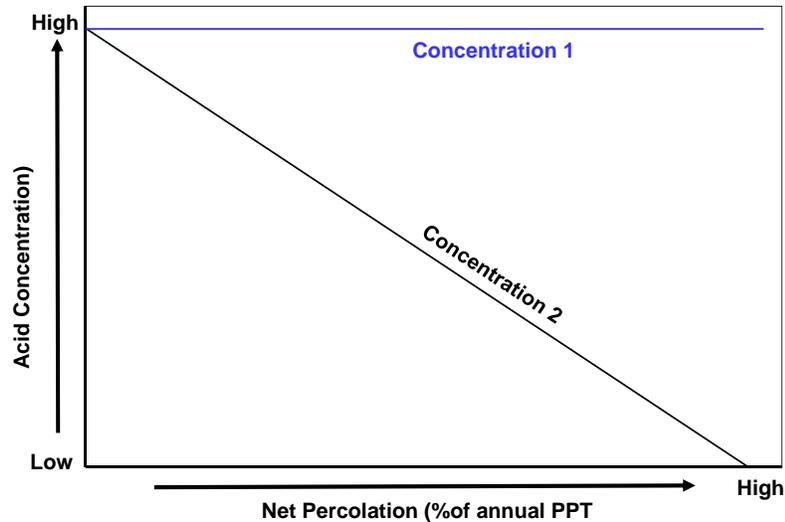


Figure 8 Acid concentration and NP relationship from conceptual models.

Model 1 (acidity load increases linearly with NP) can represent two situations where the waste storage facility contains stored acidic oxidation products that are flushed out with increasing NP where ongoing sulfide oxidation generates secondary acidic oxidation

It is likely that the mass loading from a waste rock dump will be due to some combination of solubility control (Model 1) and reaction control (Model 2). For example, early mass release may be dominated by the release of pre-existing weathering products (Model 1) followed by a longer term reaction controlled release (Model 2). Understanding the models or any transition between the models is important for cover system design and understanding acidity loads. In light of the limitations of the described conceptual models, this guidance document considers the utility of an alternate conceptual model for acidity loading, which takes into consideration the role that both oxygen ingress and net percolation can have on acidity load generation in waste storage facilities.

The conceptual basis for this combined model is that chemical load production (Load) is a function of both the rate of oxygen ingress and the rate of net percolation. The first function makes loading reaction limited while the second, solubility limited. Loading will always be zero if NP is zero; however, even if there is no oxygen ingress there could be potential loading from NP if there was an initial chemical load present due to pre-dump placement weathering. A conceptual 3D model that describes geochemical behavior is presented within the guidance that could be populated with real data to determine the best cover system design strategy. The timing of cover system employment will also determine the design as will the performance value; two aspects discussed within the geochemical load production chapter.

SITE WIDE WATER MANAGEMENT

Water occurs as a resource on the landscape, and requires a management strategy that aligns with existing or proposed closure objectives. Water resources could be in abundance to the level of becoming difficult to manage or in such scarcity requiring finite management. Generally, management of water on a specific mine feature can be divided based on three management scenarios:

1. To isolate reactive materials and diverting all water from the landform or site;
2. To capture and contain all water on a landform/ site (i.e. to prevent release to the receiving environment) and/or;
3. To utilize a portion of the water for onsite process (i.e. maintain saturated barriers or sustain vegetation), while redirecting surplus water off the landform.

In reality, a mine closure landscape may utilize all three forms of water management concurrently or in sequence throughout the closure landscape depending on specified closure objectives for each reclaimed area. Additionally, following spatially considerations for water resources, temporal considerations can be equally important. The timing and magnitude of water resources may be critical for sustaining reclamation features such as ephemeral creeks, wetlands and vegetation onsite throughout succession, and needs to be considered outside of water quantities.

Sections within the site wide water management chapter include but are not limited to landform – landscape integration and site-wide water management integration opportunities. Lack of thorough site wide water management is a common cause of permit violations, is an impediment to sustainable mine reclamation, and an added cost to mine operators. Often neglected in mine planning, integrated site wide water management planning is recommended to avoid expensive solutions and for maximizing the productive capability of the reclaimed mine landscape. One goal of integrated site wide water management planning is to provide abundant lead-time so that the reclamation landscape can be shaped concurrently with mine operations, and at lower cost.

COVER SYSTEM AND LANDFORM FIELD PERFORMANCE MONITORING

Long-term performance monitoring is critical for evaluating performance of cover systems. It is impossible to develop a single rule for how long monitoring should occur that would apply to every cover system. Instead, a cover system requires developing a monitoring strategy integrated within the design of the cover system, regulatory requirements, the needs of the mine operation and the stakeholders, and most importantly be conducted within the context of the mine closure plan.

Direct field performance measurement as part of a cover system monitoring program is the state-of-practice methodology for measuring performance of a cover system. Field performance monitoring can be implemented during the design stage with cover system field trials, or following construction of the full-

scale cover (e.g. Ayres *et al.*, 2007). Direct measurement of field performance of a cover system is the best method for demonstrating that the cover system will perform as designed

CASE STUDIES

The second half of the guidance will include case studies, used to convey the use of the proposed framework for design. Case studies are divided into two categories: 1) generic, hypothetical case studies and, 2) factual case studies.

The generic case study includes a hypothetical mine site of average to large-scale design. Reactive wastes on site are contained in a large-scale tailings storage facilities as well as a large-scale WRD. Both the TSF and WRD measure approximately 700 ha, and are representative of current large-scale facilities. To highlight the importance of climate, hydrogeological setting and microclimate, the generic mine facility components will be examined under different scenarios to determine how cover system performance is expected to be affected. Secondly, a synthesis of factual studies will aim to provide a cross section of mine sites globally in varying climates, hydrogeological setting and unique micro-climates. A one to two page fact sheet will briefly characterize each site and summarize results of the cover system to date. A lessons learned section is also included, and does not aim to highlight any failure specifically. Rather, the objective is to provide an opportunity to disseminate lessons learned on specific sites for the benefit of other sites, and propagate a knowledge base that may not have been available during the design or construction process for another site.

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