Environmental Technology in Mining

Chapter 3.3. Mining and the Environment

Carlos Rico de la Hera
Rubén Díez Montero
Ana Lorena Esteban García
Dpto. de Ciencias y Técnicas del Agua
y del Medioambiente

Environmental Technology in Mining

Chapter 3.3. Mining and the environment

Group of Environmental Engineering
Department of Water and Environmental Sciences and Technologies
Universidad de Cantabria

Content:

Section 1 - Mine atmosphere

Section 2 - Mine ventilation

Section 3 – Environmental impact and restoration in mining activities

Chapter 3.1 - Environmental technology

Chapter 3.2 - Soil pollution

Chapter 3.3 - Mining and the environment

Does mining activity have an impact on the environment?

Impact of mining activity on the environment

✓ River Cúa (León), December 1985, dead trouts in the river and in a fish-hatchery (more than 750000!)

✓ Water analysis → ↑ sulphide, ↓ pH, ↑ metals

✓ Diagnosis → metallic ions and acidity

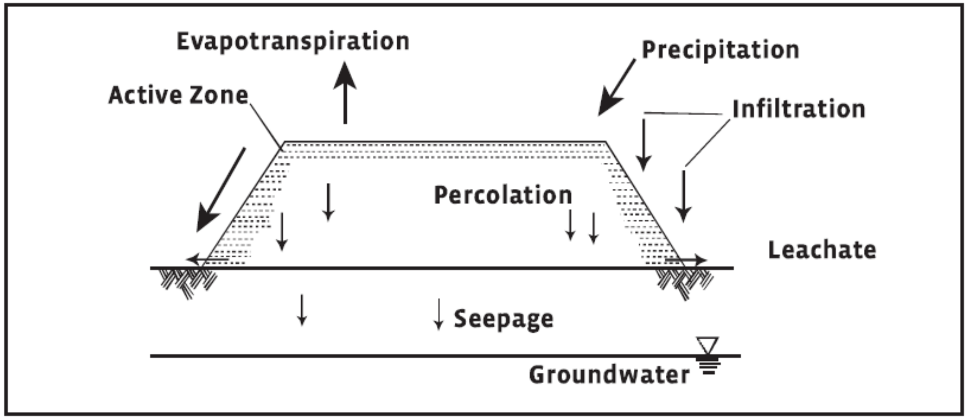
Impact of mining activity on the environment

✓ Origin of such water characteristics

→ increase of surface mining

→ sudden rainfall episode after dry weather

Impact of mining activity on the environment



Waste rock high metal and sulphide concentration (many important metal ores are sulphides: silver, mercury, lead, zinc, iron,...)

+

Sudden rainfall washes out the dumps producing **acidic water** (sulphide+oxygen+water) and dissolving **metals**

→

Acidic mine drainage (AMD) reaches the river

Impact of mining activity on the environment

► Acidic mine drainage (AMD) // or acid rock drainage (ARD)

Many metals, such as silver, mercury, lead (Pb), zinc, iron, copper, cadmium have a strong natural affinity for the element sulfur, and they combine with it to form minerals called sulphides. Probably the most familiar sulfide mineral is fool's gold (pyrite – FeS_2), which is composed of iron and sulfur.

When pyrite is exposed to air and water, it undergoes a chemical reactions (oxidation of sulphide, lowering the pH and dissolving metals). If water infiltrates into waste rock containing pyrite, the resulting oxidation can acidify the water, enabling it to dissolve metals. This production of acidic water, is commonly referred to as "**acidic mine/rock drainage (AMD or ARD)**."

FeS_2(s) + O_2(g) + H_2O(l) => low pH + dissolved metals

Impact of mining activity on the environment

Need for an appropriate management and treatment of waste and wastewater

Nowadays:

- ✓ Available **waste management** tools and strategies
- ✓ **Treatment** processes for wastewater prior to discharge

Mount Polley, British Columbia (Canada) August 2014

https://www.youtube.com/watch?v=VYYwzAvQIF8

https://www.youtube.com/watch?v=DtJPLqV6otI

Gold King Mine, Colorado (USA) August 2015

https://www.youtube.com/watch?v=qI97EY2oG0o

https://deq.utah.gov/general/gold-king-mine-2015-release

https://www.youtube.com/watch?v=x3eeZAkiBk0

Chapter 3.3. Mining and the environment:

(1) Wastewater and waste materials in mining

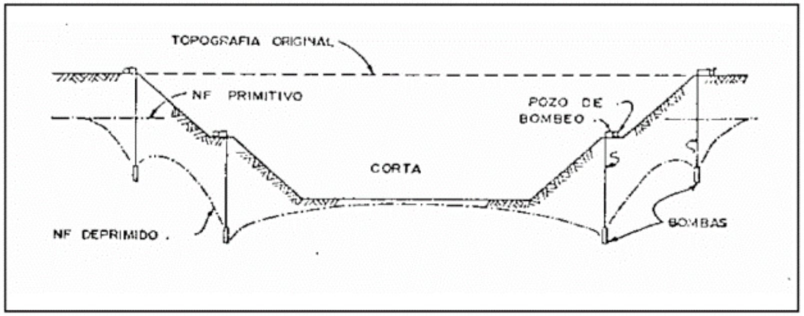
- (1.1) Wastewater sources, management and treatment
- (1.2) Waste materials, types and management

(2) Environmental impact of mining

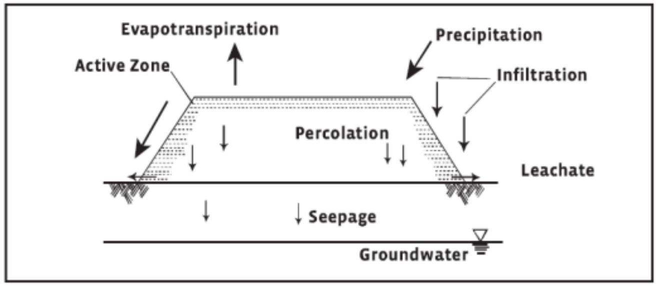
- (2.1) Major categories of impacts
- (2.2) Legislation

Main **sources** of wastewater in mining:

✓ Drainage of underground water (pumped from underground workings)



✓ Rainfall on exposed waste rock dumps (infiltration and drainage)



✓ Process water (from beneficiation: milling, leaching, flotation, etc.)

✓ Runoff from surface areas of the mine site, buildings and pavements

Wastewater management in mining:

(1) Water **quantity** depends on geological and hydrogeological factors, climate conditions, type of mining operation, etc.

(2) Water **quality** depends on geological and hydrogeological factors, type of activity (metallic/non-metallic/coal/salt/… mining, oil/gas extraction, tunneling, etc.)

Classification of water types in mining (regarding quality)

Level of contamination	Possible sources	Treatment requirement
Uncontaminated water	Runoff around the mine Drainage from areas with no acid and metals	Only suspended solids removal
Low-risk contaminanted water	Runoff from surface areas, buildings and pavements	Must be treated in a treatment plant
High-risk contaminated water	Drainage from underground workings Rainfall on exposed waste dumps containing sulphide and metal bearing rocks Process water from beneficiation	Must be treated in a treatment plant

Wastewater management in mining:

(3) In addition, **destiny** of treated and/or uncontaminated water could be…

→ use/reuse in mining activity?

→ discharge into surface water bodies?

→ discharge into sewer system?

→ recharge of aquifers?

→ water supply for urban and industrial uses?

↳ Treatment **objectives**: according to the quality objectives for the receiving body (discharge permit) or reuse

Take home messages:

(1) Wide variety of wastewater characteristics

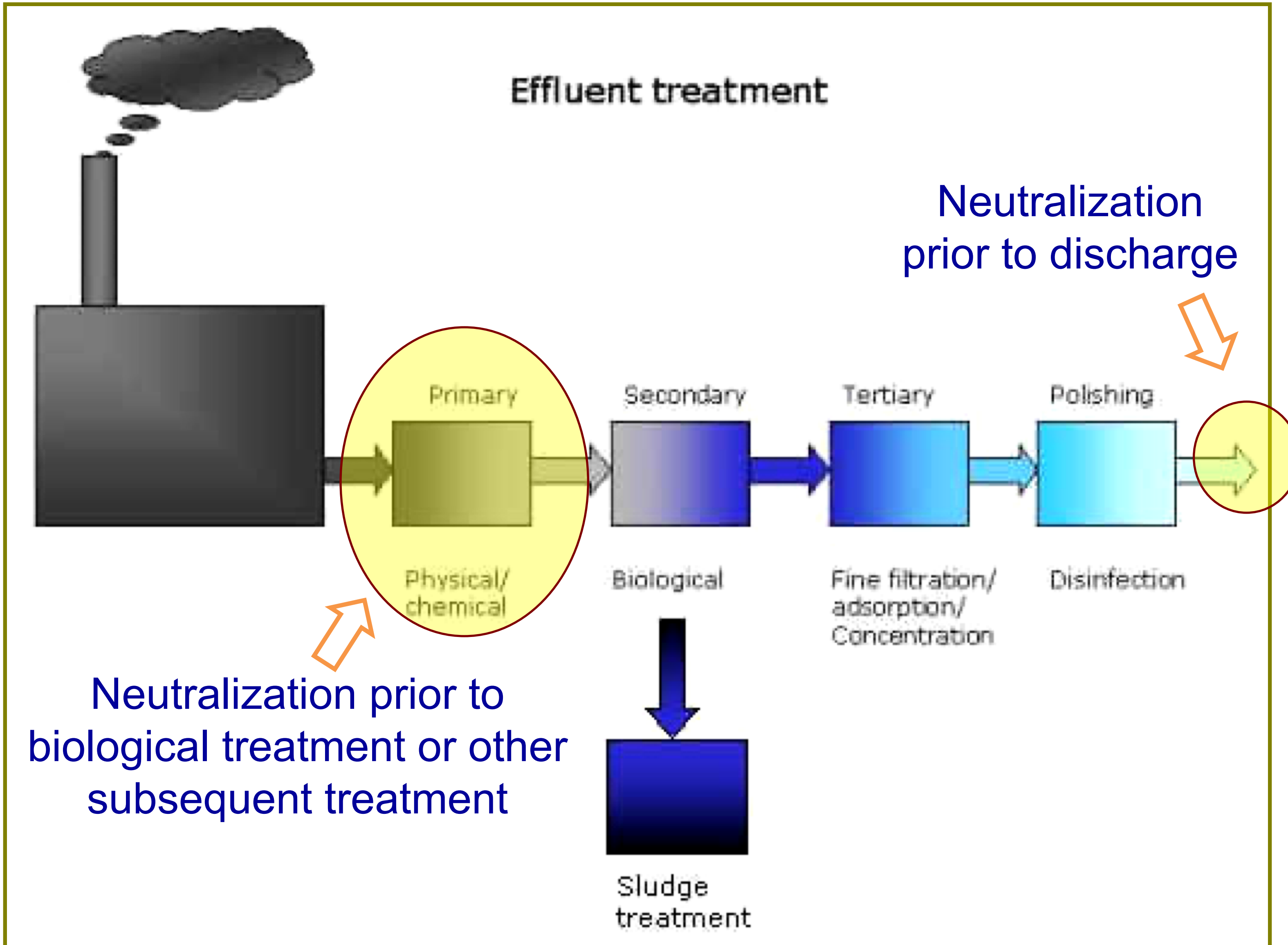
(2) Possible separation by type (segregation)

(3) Different treatment requirements

- Neutralization is **the reaction of an acid and a base, which forms water and a salt**.
- We apply it to avoid acidic (<<7) or alkaline (>>7) conditions in water.

Acidic or alkaline wastewaters require **neutralization** prior to:

- ✓ Discharge into receiving waters
- ✓ Chemical subsequent treatment sensitive to pH
- ✓ Biological treatment (pH = 6.5-8.5)


Effluent treatment
Neutralization
prior to discharge
Primary
Secondary
Tertiary
Polishing
Physical/
chemical
Biological
Fine filtration/
adsorption/
Concentration
Disinfection
Neutralization prior to
biological treatment or other
subsequent treatment
Sludge
treatment

Chemical **reaction** for neutralization:

- ✓ Acid + Base → Salt + H_2O

$$H_2SO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + 2H_2O$$

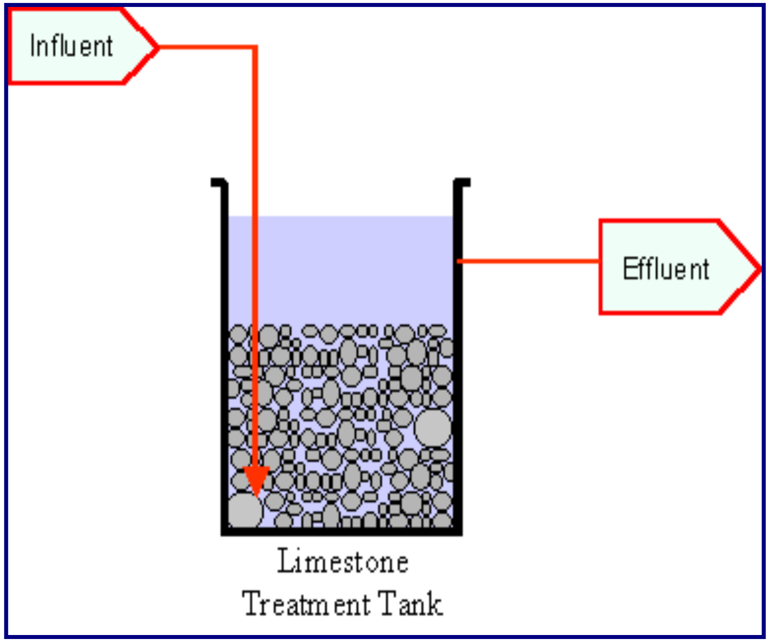
$$HCl + Ca(OH)_2 \longrightarrow CaCl_2 + 2H_2O$$

Types of processes:

- ✓ Mixing acidic and alkaline wastestreams
- ✓ Acidic wastewater neutralization through limestone bed
- ✓ Mixing acid wastewater with lime slurry
- ✓ Mixing basic (alkaline) wastewater with acid

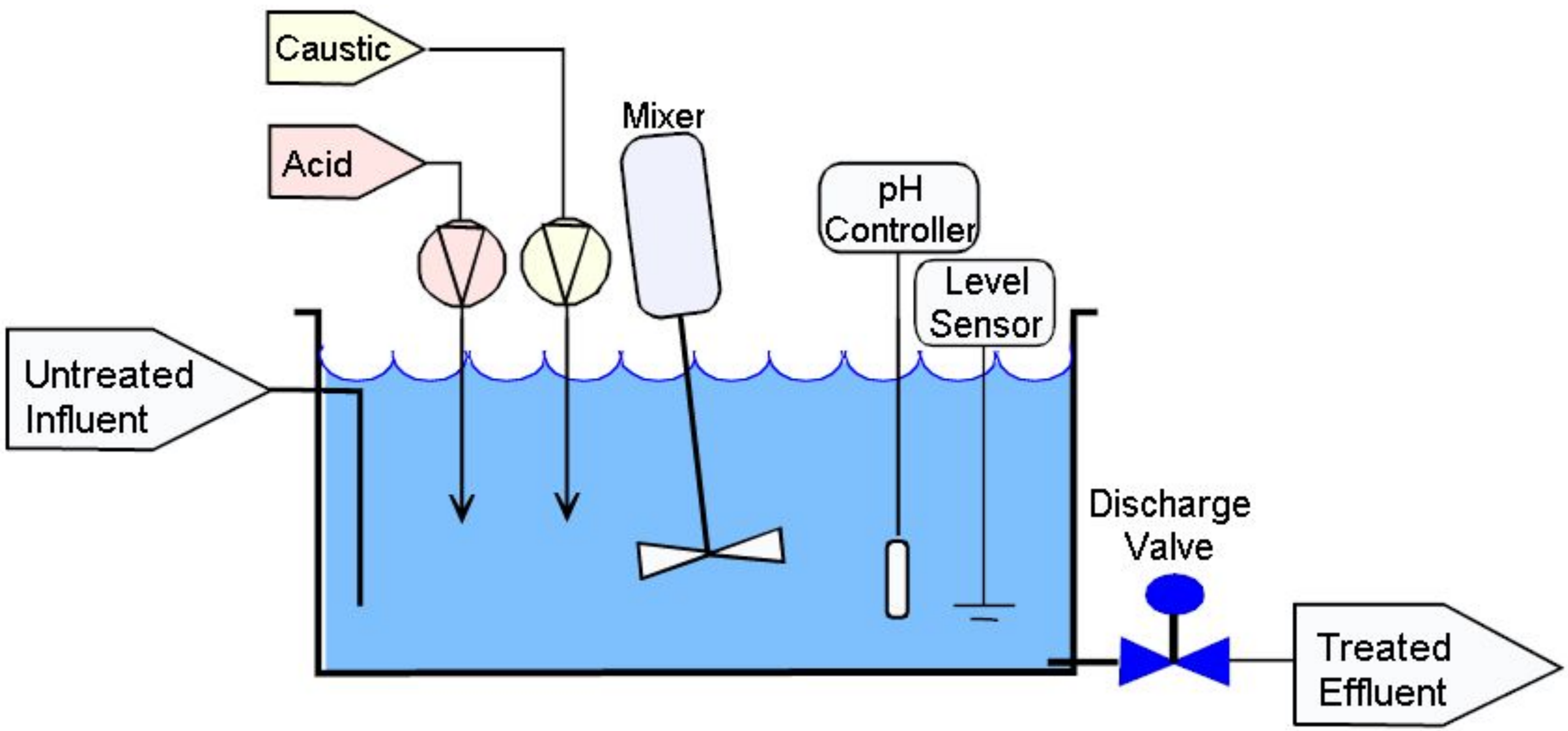
Neutralization through limestone bed:

- ✓ Consists in passing the acidic wastewater through a limestone bed (in a tank, basin, etc.).
- ✓ Depth ≈ 1 m. Downflow or upflow
- ✓ Hydraulic surface loading < 40 L/min·m^2
- ✓ Some disadvantages: useless for alkaline wastewater, process control is not possible, limestone needs to be replaced.



Mixing acidic wastewater with lime slurry:

- ✓ Consists of a reaction tank, for wastewater and **lime** mixing
- ✓ Can also be accomplished using NaOH, Na_2CO_3, NH_4OH or others
- ✓ Reaction time ≈ 10 min

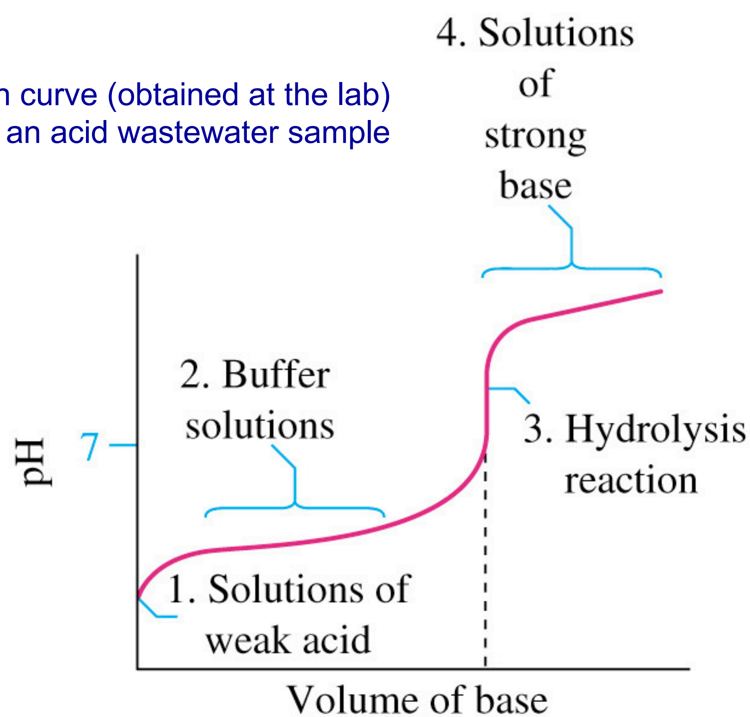


Mixing acidic wastewater with lime slurry:

- ✓ Consists of a reaction tank, for wastewater and **lime** mixing
- ✓ Can also be accomplished using NaOH, Na_2CO_3, NH_4OH or others
- ✓ Reaction time ≈ 10 min
- ✓ Amount of chemical/reagent → titration curve is needed (pH vs. volume)

pHmeter

Titration curve (obtained at the lab) of an acid wastewater sample

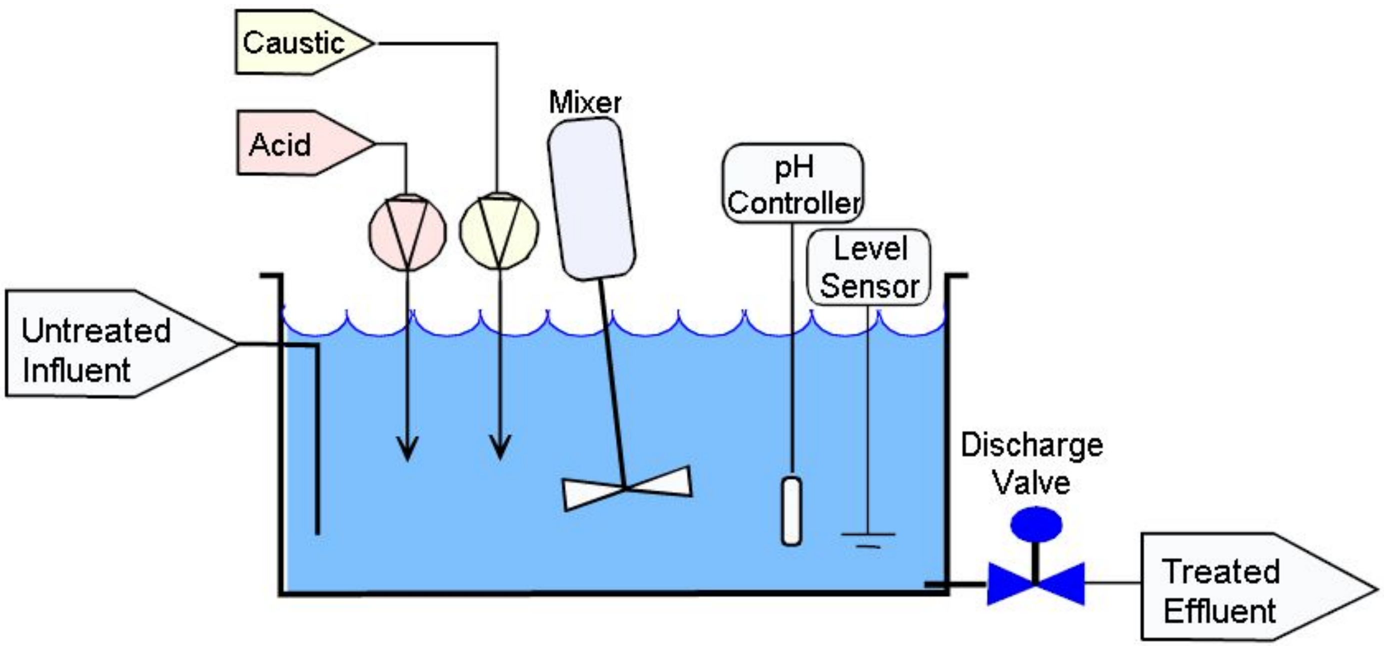


Titration Data

mL NaOH(aq)	pH
0.00	2.89
5.00	4.14
10.00	4.57
12.50	4.74
15.00	4.92
20.00	5.35
24.00	6.12
25.00	8.72
26.00	11.30
30.00	11.96
40.00	12.36
50.00	12.52

Mixing basic (alkaline) wastewater with acid:

- ✓ Consists of a reaction tank, for wastewater and **acid** mixing
- ✓ Strong acids can be used, usually H_2SO_4 and HCl
- ✓ Bubbling CO_2 can also be used (forms H_2CO_3)
- ✓ Reaction time practically instantaneous

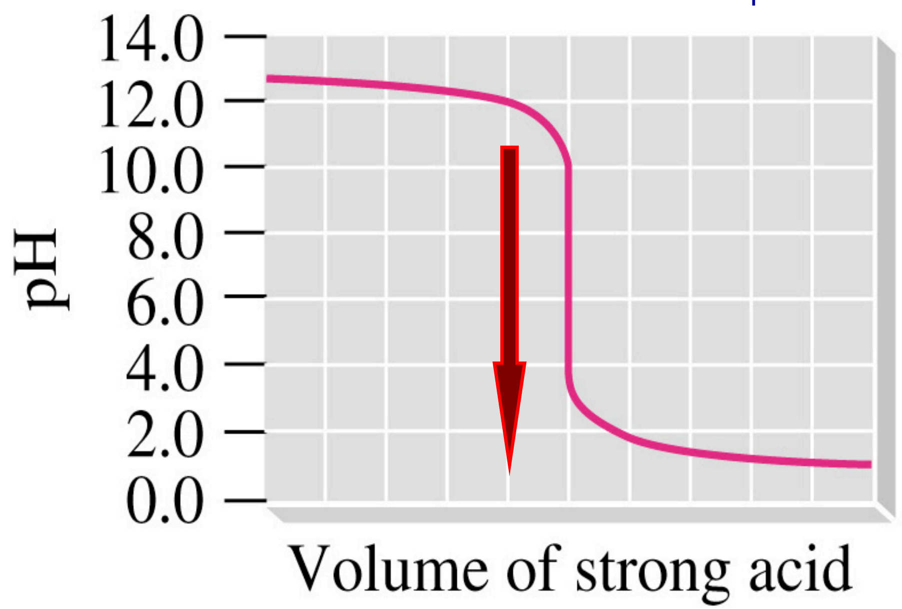


Mixing basic (alkaline) wastewater with acid:

- ✓ Consists of a reaction tank, for wastewater and **acid** mixing
- ✓ Strong acids can be used, usually H_2SO_4 and HCl
- ✓ Bubbling CO_2 can also be used (forms H_2CO_3)
- ✓ Reaction time practically instantaneous
- ✓ Amount of chemical/reagent → titration curve is needed

pHmeter

Titration curve (obtained at the lab) of an alkaline wastewater sample

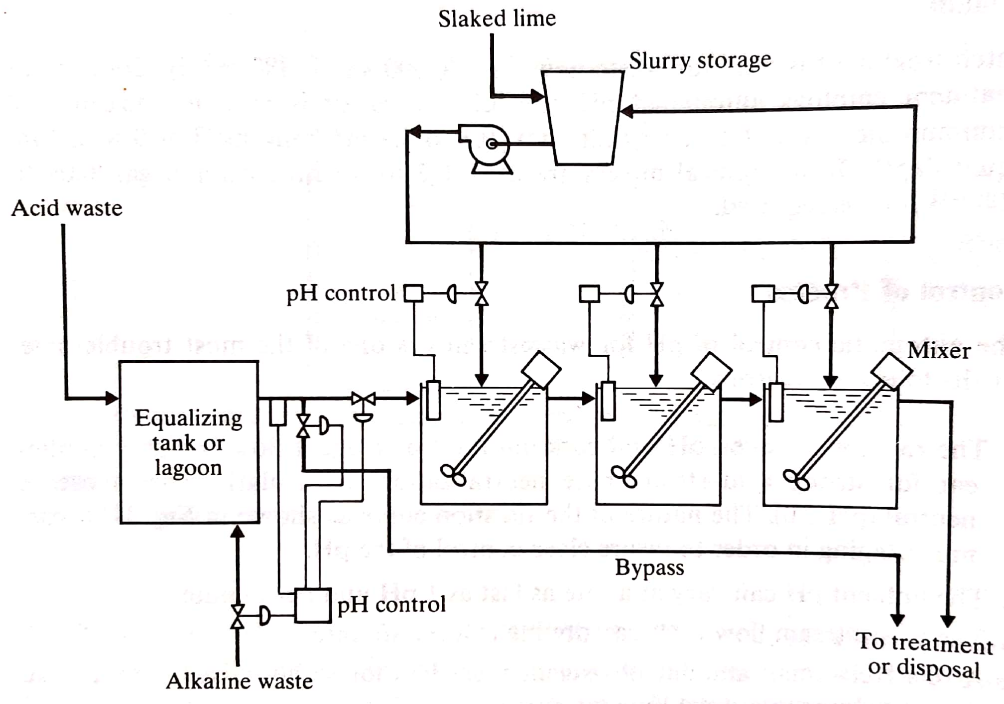


Process design considerations:

- ✓ Reaction tank (batch or continuous treatment):

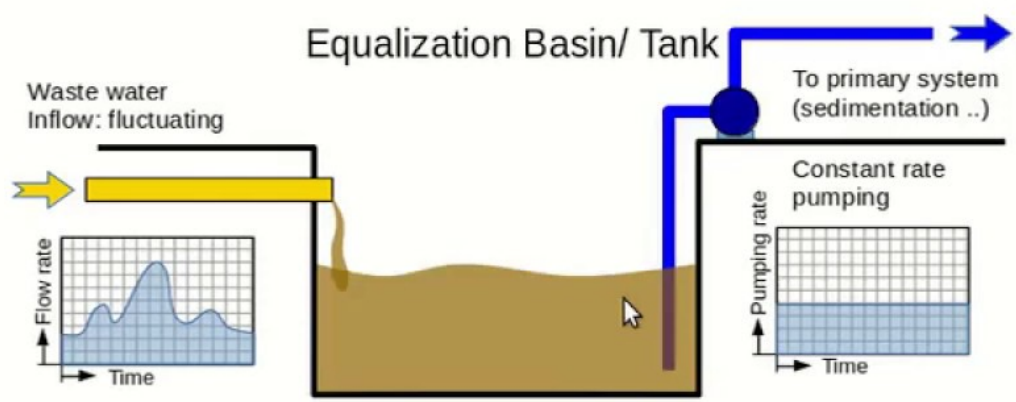
  Hydraulic Retention Time (HRT) = few minutes ≈ 10 minutes

- ✓ **Mixing** requirements (acceptable not only for neutralization):
  - ✓ Air: 0.3-0.9 $m^3/min \cdot m^2$
  - ✓ Mechanical mixer: 40-80 W/m^3
- ✓ Automatic control of pH, troublesome:
  - ✓ Relation pH-reagent volume **highly nonlinear**
  - ✓ Influent flowrate and pH **fluctuations**
- ✓ Recommended:
  - ✓ **Stepwise addition** of chemicals (2 or 3 stages)
  - ✓ Neutralization in **equalization tank**



Stepwise addition of lime (3 stages)

Equalization tank for wastewater



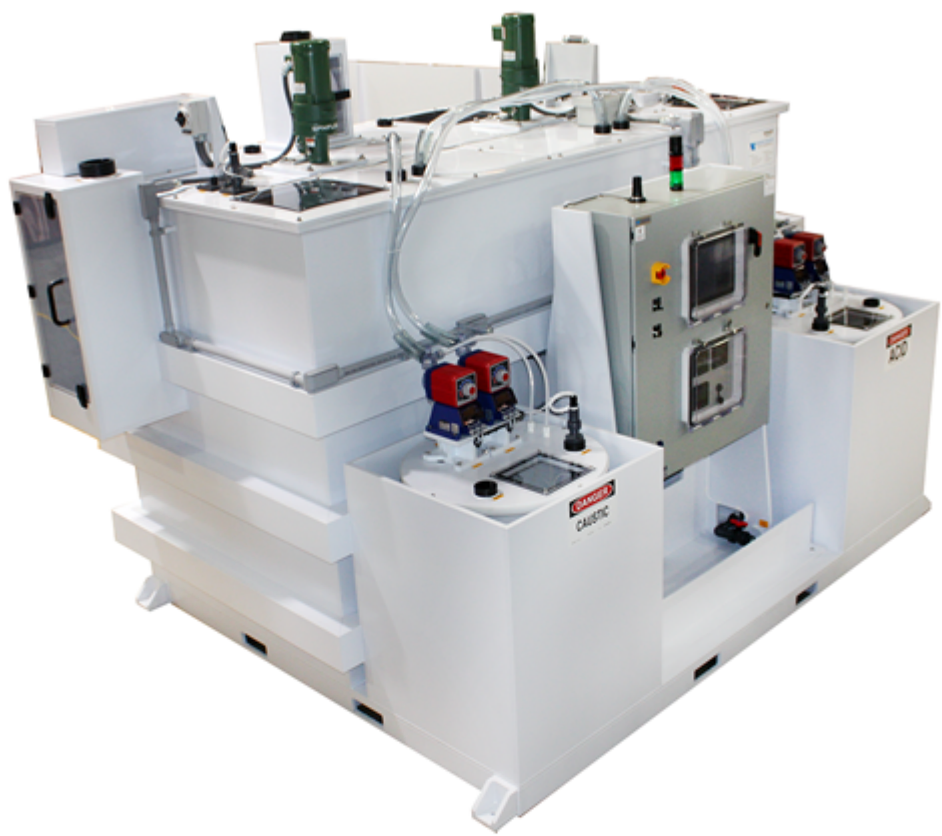
Single-stage neutralization compact unit

Single-Stage Continuous Neutralization Systems

- Up to 500 GPM (≈ 1900 L/min)
- Acidic or alkaline wastewater
- Fully automatic pH adjustment with continuous chart recording
- Factory assembled with single inlet and outlet

WASTECH CONTROLS & ENGINEERING, INC. *(www.wastechengineering.com)*

Two-stages neutralization compact unit



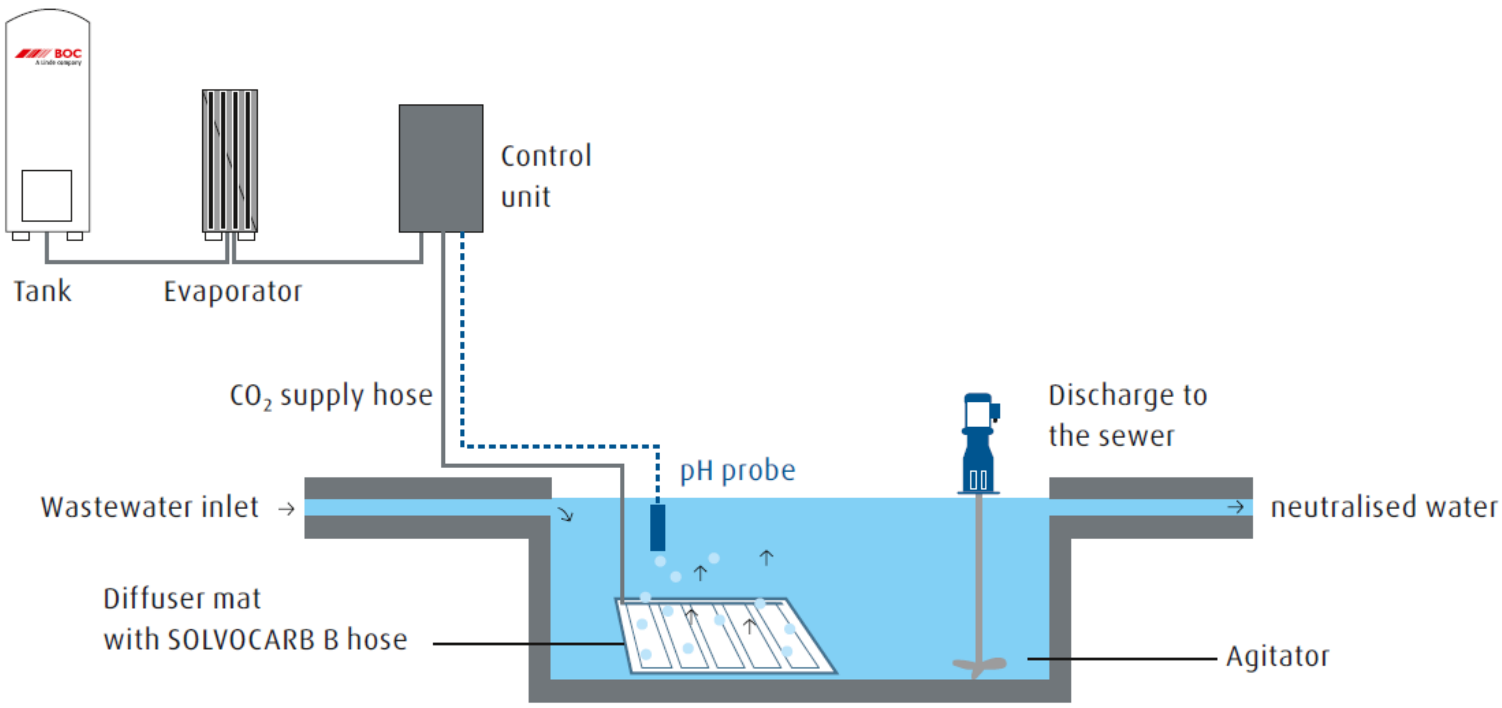
Two-Stage Continuous Neutralization Systems

- Up to 400 GPM (≈ 1500 L/min)
- Extreme wastewater conditions (pH 3-11)
- Fine tuning of pH effluent
- Fully automatic pH adjustment with continuous chart recording

WASTECH CONTROLS & ENGINEERING, INC.

(www.wastechengineering.com)

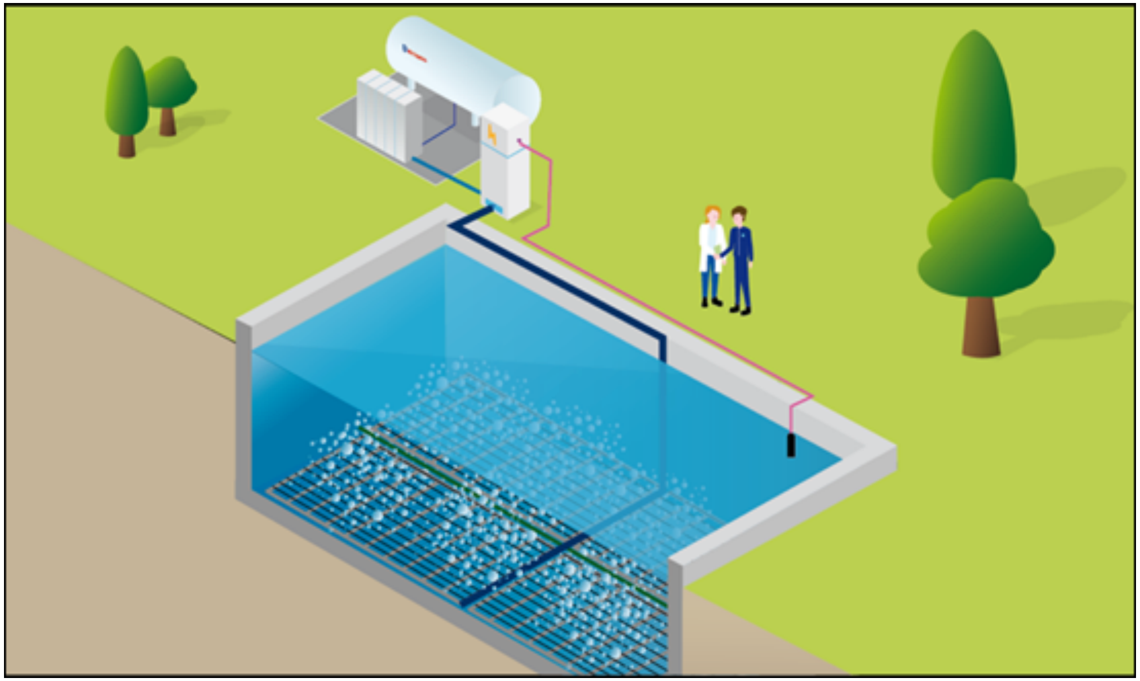
Neutralization of alkaline wastewater carried out in an equalization tank by means of CO_2 injection



BOC
A Linde company

(www.boconline.co.uk/en/images/BOC-Solvocarb-Data-Sheet_tcm410-98697.pdf)

Neutralization of alkaline wastewater carried out in an equalization tank by means of CO_2 injection



Air Liquide

(www.blog.airliquide.co.uk/united-kingdom/item/continuity/manufacturing-process/why-use-co2-wastewater-treatment-plants)

Important heavy metals:

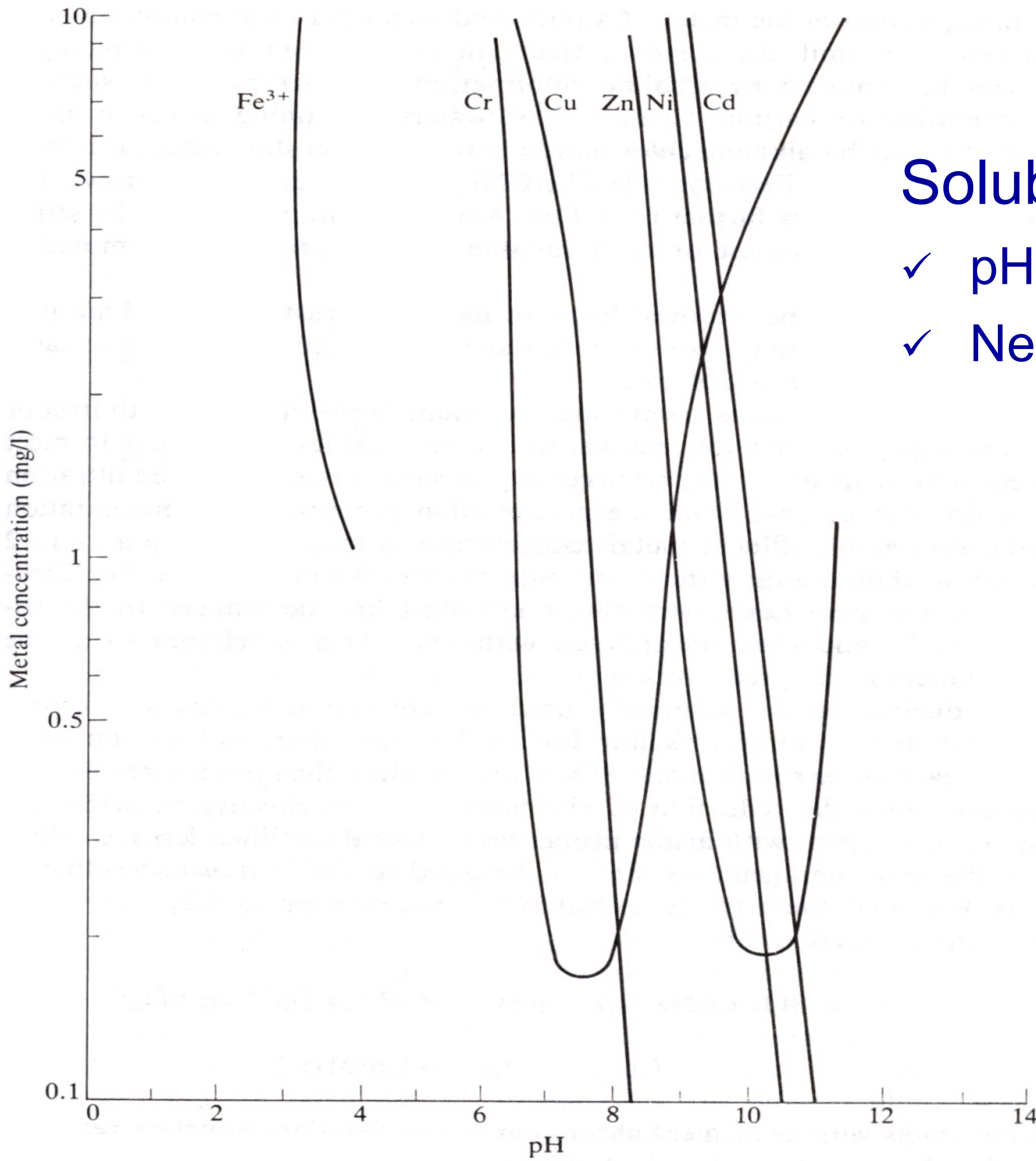
Fe, As, Cd, Cr, Ni, Cu, Pb, Mn, Co, Hg, Se, and Zn

Mining sites are one of the most significant **sources of heavy metals**: they are present in mining water from
(i) acidic mine drainage
(ii) drainage of underground water
(iii) process water

High **environmental impact**:

- Toxic to aquatic organisms
- Contamination of drinking water resources
- Bioaccumulation in the food chain

- ✓ Fundamentals of heavy metals removal:
  - ✓ **Chemical precipitation** is used for the removal of heavy metals from wastewater, based on the reduction of solubility by increasing the pH
  - ✓ Generally precipitated as hydroxide through the **addition of lime** ($Ca(OH)_2$) **or caustic soda** (NaOH) to a pH of minimum solubility
  - ✓ Different **pH of minimum solubility** for different metals
  - ✓ Several metals are amphoteric and exhibit a point of minimum solubility (Cr, Zn)
  - ✓ Heavy metals may also be precipitated as the sulphide and in some cases as the carbonate
  - ✓ Reaction tank (mixing) followed by a settling tank (separation of water and particles)
  - ✓ In some cases it may be necessary to provide final filtration → low effluent requirements



Solubility of metals vs. pH:

- ✓ pH ≤ 5 → high solubility
- ✓ Need to reduce ≈ C ≤ 1 mg/L

Precipitation of heavy metals

1st) Preparation of $Ca(OH)_2$: slaking

$$CaO\ (s) + H_2O \rightarrow Ca(OH)_2$$

a) example: precipitation of Fe as $Fe(OH)_3$ with addition of $Ca(OH)_2$

$$Fe^{3+} + \mathbf{3OH^-} \rightleftharpoons Fe(OH)_3\ (s)$$

(similarly for all metals 3 valence)

b) example: precipitation of Cu as $Cu(OH)_2$ with addition of $Ca(OH)_2$

$$Cu^{2+} + \mathbf{2OH^-} \rightleftharpoons Cu(OH)_2\ (s)$$

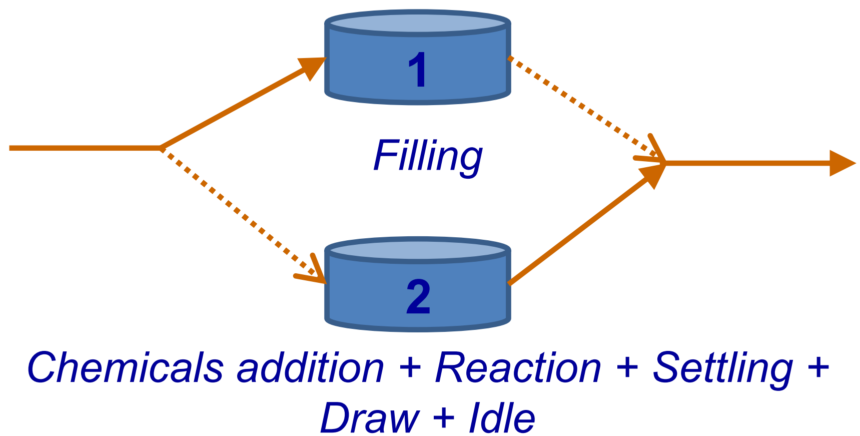
(similarly for all metals 2 valence)

Metal	$Ca(OH)_2$ theoretical quantity (g/g metal)
Fe	1.99
Cr	2.13
Cu	1.16
Zn	1.13

✓ Heavy metals removal systems:

✓ For **small plants** (≈ Q≤100 m^3/d) the most economical system is **batch** treatment → two tanks in parallel, with daily flow capacity

Batch operation, 2 parallel tanks
(tank 1: filling; tank 2: treatment) :

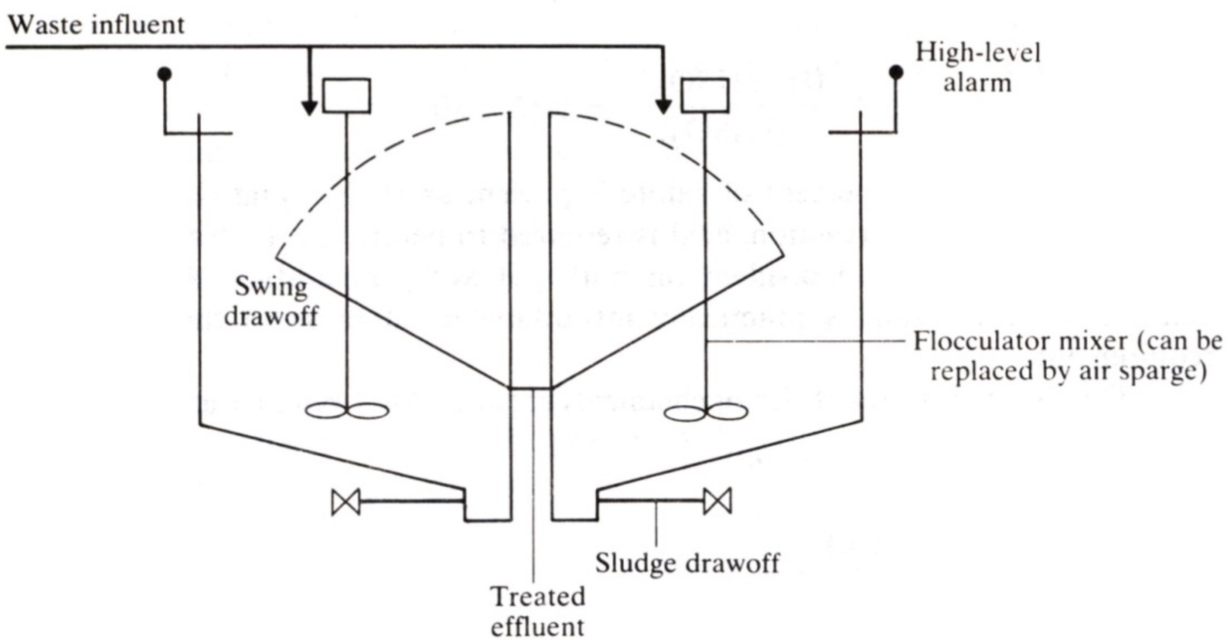


	Day i	Day i+1
TANK 1	*Filling*	*Add + React + Sett + Draw + Idle*
TANK 2	*Add + React + Sett + Draw + Idle*	*Filling*

✓ Heavy metals removal systems:

✓ For **small plants** (≈ Q≤100 m^3/d) the most economical system is **batch** treatment → two tanks in parallel, with daily flow capacity

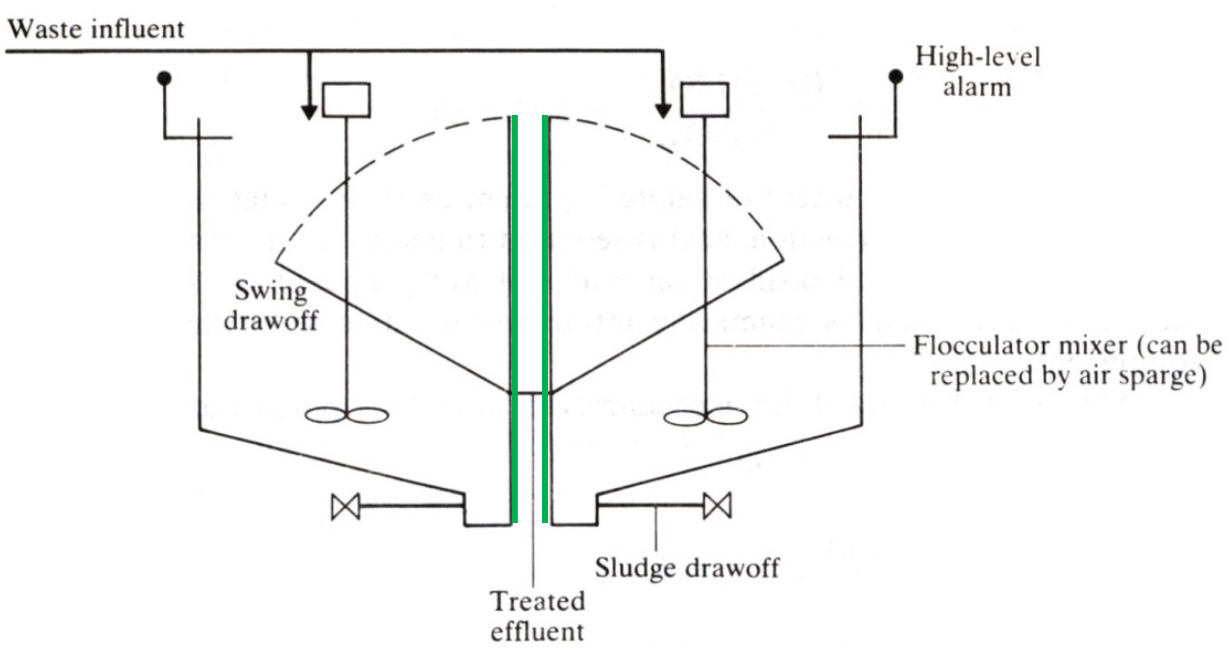
Example of batch tank:



✓ Heavy metals removal systems:

- ✓ For **small plants** (≈ Q≤100 m^3/d) the most economical system is **batch** treatment → two tanks in parallel, with daily flow capacity

Example of batch tank:

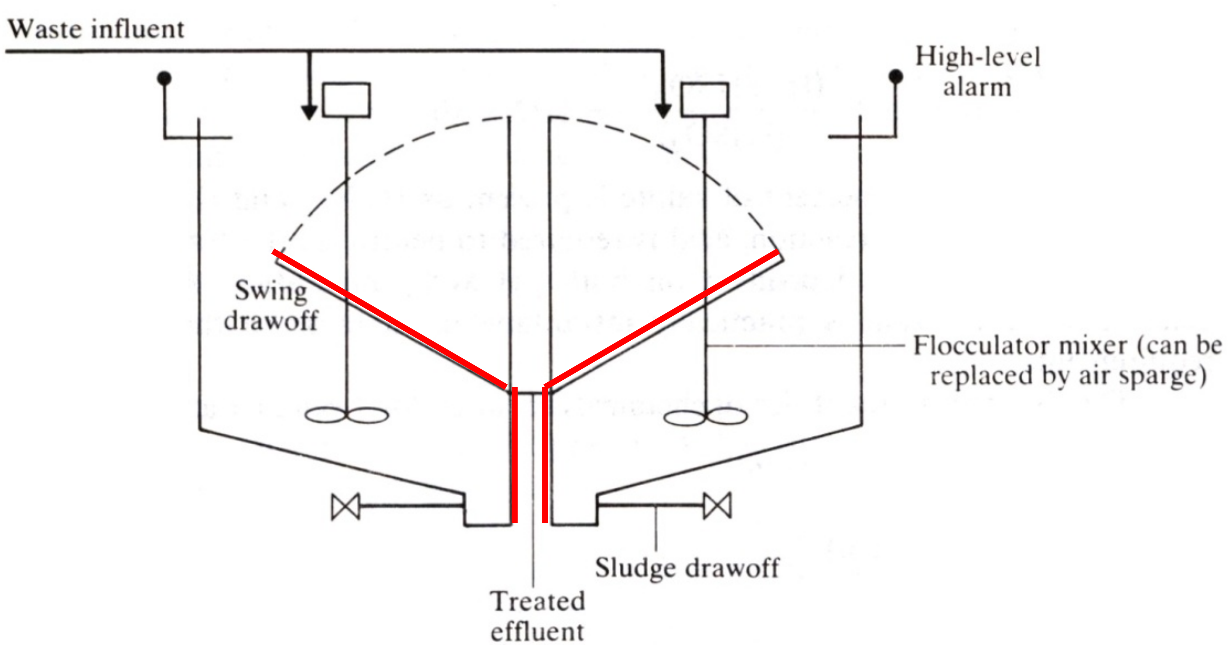


Filling + Add + React + Sett

✓ Heavy metals removal systems:

✓ For **small plants** (≈ Q≤100 m^3/d) the most economical system is **batch** treatment → two tanks in parallel, with daily flow capacity

Example of batch tank:

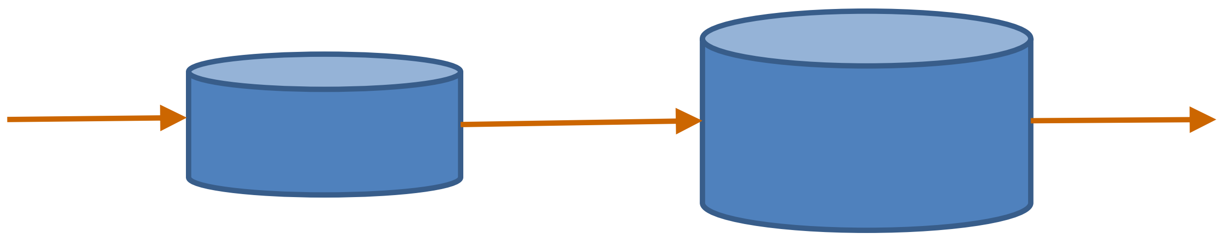


Draw

✓ Heavy metals removal systems:

- ✓ For **large plants** (≈ $Q>100\ m^3/d$) batch treatment not feasible because too large tanks are required
- ✓ Continuous treatment → Mixing tank + Settling tank

Continuous operation:



Mixing/reaction tank
HRT ≈ 20 min

Settling tank
HRT ≈ several hours

- ✓ Instrumentation and **automatic control of pH** are required

Use of constructed wetlands for treatment of mine effluents:

- ✓ The need for **conventional treatment** of mine effluents can make business **unprofitable** (high operational cost)
- ✓ **Passive systems** → minimize input of energy, materials and manpower, and so reduce operational costs (they use naturally available energy sources: topographic gradient, microbial metabolic energy, photosynthesis,…)

Use of constructed wetlands for treatment of mine effluents:

- ✓ In **constructed wetlands**, natural processes are used to abate the polluted waters: neutralization and heavy metals removal by oxidation, hydrolysis and reduction of metal cations, and uptake by plants
- ✓ The treatment system can be **integrated aesthetically** into the surrounding environment
- ✓ However, not useful for all types of mine waters

Skousen et al. (2016) Review of Passive Systems for Acid Mine Drainage Treatment

- **Acidic mine drainage (AMD)**: phenomenon producing acidic water due to the combination of (sulphide+oxygen+water)
- Mining and other industrial activities produce a **wide variety of wastewater characteristics** (quantity and quality) with **different treatment requirements** (depending on the destiny)
- Need for an **appropriate management and treatment** of waste and wastewater subject to **specific requirements**, which could lead to **segregation**
- Acidic wastewater neutralization in **limestone bed**
- Acidic wastewater neutralization by **mixing with lime**
- Alkaline wastewater neutralization by **mixing with acid** (or CO_2)
- Description of **batch** and **continuous** operation
- Meaning and expression of **HRT**
- Fundamentals of **heavy metals precipitation** with lime
- **Preliminary design of neutralization and heavy metals precipitation** processes and amount of chemicals required

Limestone: roca caliza

Calcium carbonate: $CaCO_3$ (ES: carbonato cálcico)

Calcium hydroxide / hydrated lime: $Ca(OH)_2$ (ES: cal hidratada)

Quicklime / lime: CaO (ES: cal viva)

Slaking: $CaO + H_2O \rightarrow Ca(OH)_2$ (ES: apagado)

Sodium carbonate / soda ash / soda: Na_2CO_3 (ES: sosa Solvay)

Sodium hydroxide / caustic soda: NaOH

Carbonic acid: H_2CO_3 (ácido carbónico)

Sulfuric acid: H_2SO_4 (ácido sulfúrico)

Hydrochloric acid: HCl (ácido clorhídrico)

Ammonium hydroxide: NH_4OH (hidróxido amónico)

Sulphate: SO_4^{2-} (sulfato)

Sulphide: S^{2-} (sulfuro)

Waste materials, types and management:

- Types of solid wastes and materials in mining
  - ✓ Overburden and waste rock
  - ✓ Tailings
  - ✓ Spent ore, heap and dump leach residues
- Waste rock and overburden management
- Tailings management
- Spent ore/heap and dump leach management

- Background:

Mining operations produce a variety of **solid materials** that require **permanent management** (disposal methods, location of disposal facilities and engineering designs of disposal facilities)

- **Types of solid wastes and materials** in mining:
  - Overburden
  - Waste rock
  - Tailings
  - Spent ore, heap and dump leach residues

- ✓ Background:

Mining operations produce a variety of **solid materials** that require **permanent management** (disposal methods, location of disposal facilities and engineering designs of disposal facilities)

- ✓ Types of solid wastes and materials in mining:
  - ✓ Overburden
  - ✓ Waste rock
  - ✓ Tailings
  - ✓ Spent ore, heap and dump leach residues

✓ Background:

Mining
material
(disposa
and en

✓ Types of solic

✓ Overburden

✓ Waste rock

✓ Tailings

✓ Spent ore, h

Overburden: unconsolidated and poorly consolidated materials such as soils and alluvium that must be removed to access the ore body that will be mined and processed.

Potential pollution:

✓ In most cases, overburden materials will not contain significant quantities of leachable metals or acid-generating minerals.

✓ However, geochemical tests may need to be conducted to ensure the benign character of these materials.

✓ Unconsolidated materials may require proper handling and disposal to prevent erosion, dust and sediment loading to streams and other surface waters.

- ✓ Background:

Mining operations produce a variety of **solid materials** that require **permanent management** (disposal methods, location of disposal facilities and engineering designs of disposal facilities)

- ✓ Types of solid wastes and materials in mining:
  - ✓ Overburden
  - ✓ Waste rock
  - ✓ Tailings
  - ✓ Spent ore, heap and dump leach residues

- ✓ Background:

Mining
materials
(disposal
and engi

- ✓ Types of solid
  - ✓ Overburden
  - ✓ Waste rock
  - ✓ Tailings
  - ✓ Spent ore, hea

Waste rock: material removed from above or within the ore during mining activities, including granular, broken rock and soils. These materials may be designated as waste because they contain too low concentration of the target mineral, or it is present in a form that cannot be processed with the existing technology.

Potential pollution:

✓ May be acid generating and may contain metals that can be mobilized and transported into the environment.

✓ Geochemical tests, required to determine the potential environmental impact.

✓ Handling and disposal procedures, and closure plans may be required.

- ✓ Background:

Mining operations produce a variety of **solid materials** that require **permanent management** (disposal methods, location of disposal facilities and engineering designs of disposal facilities)

- ✓ Types of solid wastes and materials in mining:
  - ✓ Overburden
  - ✓ Waste rock
  - ✓ Tailings
  - ✓ Spent ore, heap and dump leach residues

✓ Background:

Minin
materi
(dispos
and e

✓ Types of sol

✓ Overburde

✓ Waste rock

✓ Tailings

✓ Spent ore,

Tailings: residue from beneficiation activities that separate the target minerals or metals from the remaining host rock. Beneficiation begins when primary ore is crushed. Target minerals are separated from the ore using density or magnetic separation, froth flotation, or other concentration techniques. The target metal is then separated from the mineral by leaching, electrowinning, or other metallurgical techniques.

Potential pollution:

✓ Tailings may make up to 90% of the original ore mined.

✓ Composition depends on mineralogy and the type and efficiency of the separation process.

✓ Based on the original constituents, tailings may contain acid-generating minerals and a variety of metals.

✓ Background:

Mining operations produce a variety of **solid materials** that require **permanent management** (disposal methods, location of disposal facilities and engineering designs of disposal facilities)

✓ Types of solid wastes and materials in mining:

- ✓ Overburden
- ✓ Waste rock
- ✓ Tailings
- ✓ Spent ore, heap and dump leach residues

✓ Backgrour

Mir
mate
(disp
and

✓ Types of s

✓ Overbur

✓ Waste ro

✓ Tailings

✓ Spent ore, heap and dump leach residues

Spent ore, heap and dump leach residues: some primary ores (notably those of copper and gold) may be processed by heap or dump leaching techniques. Leaching is the process of applying a leach agent (usually water, acid or cyanide) to piles of ore to extract the valuable metal(s) by leaching over a period of months or years.

Potential pollution:

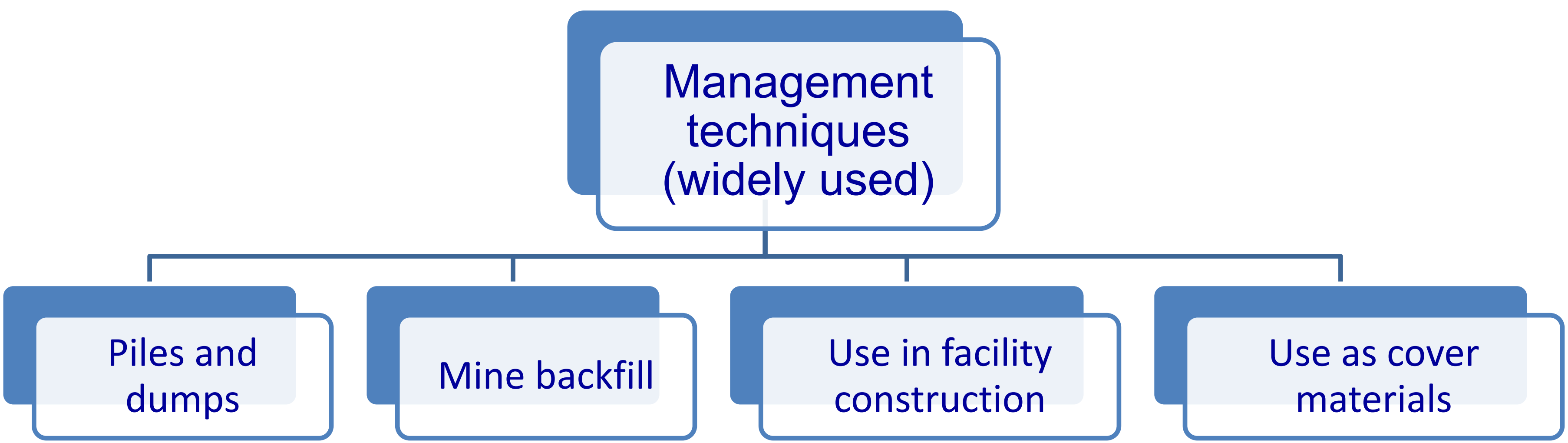
✓ Spent materials contain lower concentration of the target mineral, may contain other minerals, acid-generating minerals, and small quantities of the leach solution.

✓ Other residues are generated when treating the spent ore (rinsing with water or chemicals).

✓ Waste rock and overburden management:

- ✓ Waste rock and overburden are usually managed **together**
- ✓ It should be managed **according to**:
  - specific site conditions
  - regulatory requirements
  - materials composition

→ Management practices that are suitable at one site may be unsuitable at another



✓ Piles and dumps:

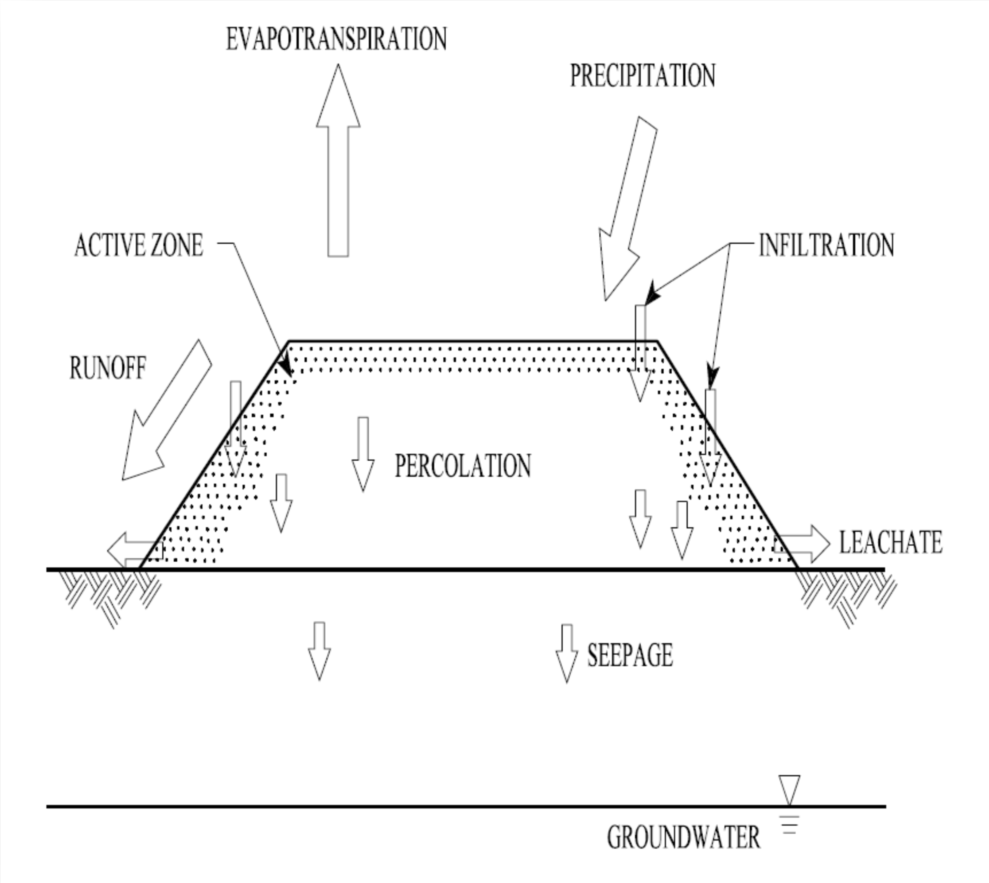
Waste rock and overburden that:

✓ Cannot be put to beneficial use

or

✓ Contain compounds that may be detrimental to the environment

→ Placed in piles/dumps
(where they can be physically stabilized, avoiding/reducing environmental impacts, even after mine closure)

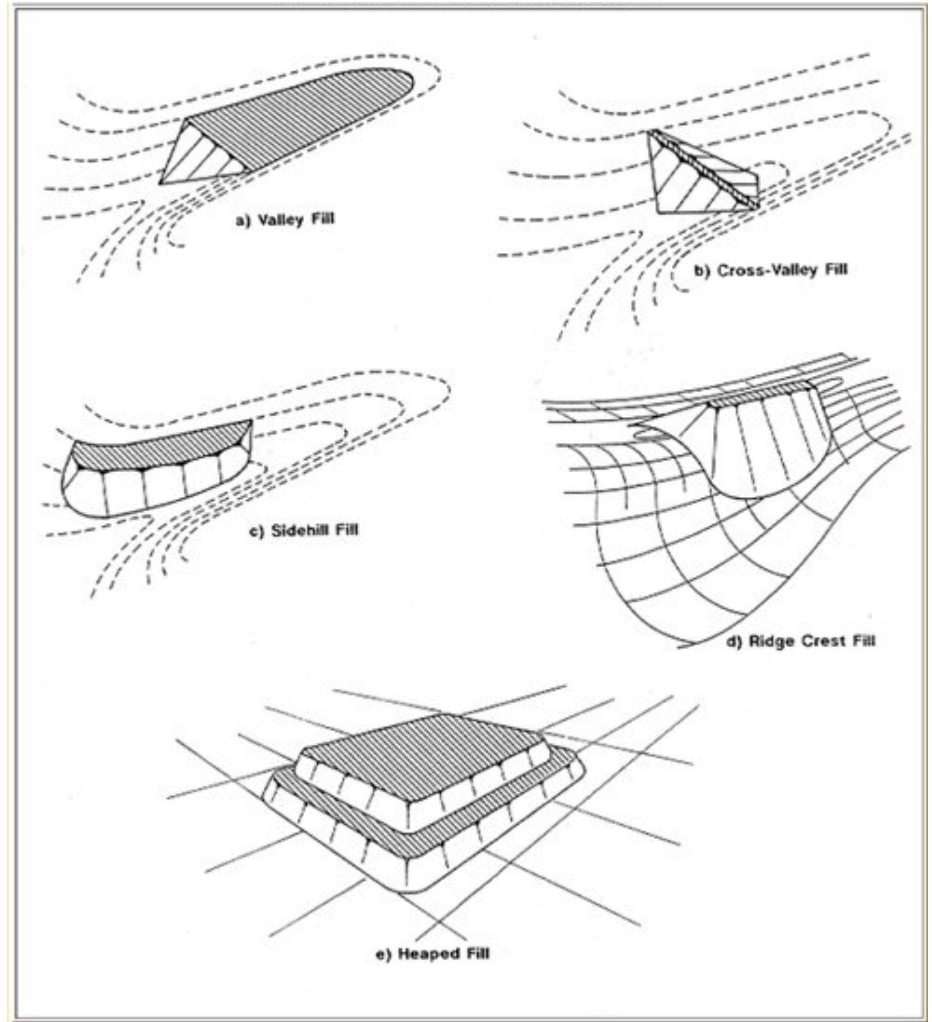


Hydrologic cycle for a typical waste rock pile

✓ Piles and dumps:

✓ **Design** of piles and dumps:

- Dump design may vary depending on the nature of the mining operation and the terrain in which materials are being placed
- Valley fill dumps may require underdrains to convey the flow of water through the drainage to treatment facilities
- Dumps containing waste rock capable of releasing metals, acidity, or other constituents may require special design features to reduce and control acidic mine drainage



Types of mine dumps

✓ Piles and dumps:

Data needs for waste rock disposal facilities

Critical design factor	Data needs	Data source/Methodologies
Facility site selection	Topography	Topographical maps, aerial photos
	Geology and soils	Geological maps
	Seismicity (natural and blasting-induced)	Geological maps, seismic zone maps, mine plan of operation
	Surface and ground water hydrology	Precipitation, runoff, ground water
	Operational considerations	Mine plan of operation
Waste rock characteristics	Physical and chemical properties	Characterization tests
Pile/Dump construction	Foundation and pile stability	Geotechnical and engineering tests of site soil samples and waste rock materials
	Seepage and run-off collection and treatment	Quantity and quality of water discharged from waste rock materials

✓ Piles and dumps:

Operational monitoring of waste rock dumps

Type of monitoring	Methods used	Purpose
Geotechnical	Visual inspection, extensiometer,…	Detect changes in slope stability, compaction, and settling that may identify structural weaknesses or signal potential failure of the facility
Surface and ground water	Runoff monitoring (upstream and downstream water quality analyses) and water table monitoring (upgradient and downgradient water quality analyses)	Detect impacts to surface and ground water quality
Hydraulic	Precipitation/infiltration measurements, piezometers,…	Detect development of water table within pile, identify fluid pathways
Thermal	Temperature probes	Detect temperature increases within the pile that may indicate oxidation processes
Pore water	Water quality analyses	Determine quality of leachate, early detection of acidification

✓ Mine backfill

Mine backfilling is the act of transporting and placing overburden and waste rock in surface or underground mines, minimizing the surface disturbance to store waste materials:

- Mine voids can accommodate up to aprox. 70% of the original material (due to the increase in rock volume that occurs through blasting and excavation).
- Physical and chemical characteristics of backfill materials should be previously analyzed.
- If necessary, impermeable liner and water drain collection should be implemented.
- A monitoring program should be planned.

Surface mine backfill

✓ Use in facility construction

Waste rock and overburden can be beneficially used as construction materials to construct roads, impoundments, buttresses, and others:

- These materials should not generate acid or other environmental impacts.
- Physical (size distribution, moisture content) and chemical (acid generation potential, metals concentrations) characteristics of the materials should be previously analyzed.
- A monitoring program should be planned.

Haul truck carries waste rock in a copper mine

✓ Use as cover materials

Uncovered (up) and covered (down) mine tailings

Waste rock and overburden may be used to cover and stabilize fine-grained tailings:

- The intent is to reduce or prevent erosion, transport, and redeposition of the fine-grained materials (due to runoff and/or wind).
- It is desired that the cover material has the ability of supporting vegetation.
- Geochemical evaluation of the waste rock/overburden that allows prediction of changes in water quality of infiltrating precipitation and of any runoff, should be previously provided.
- A monitoring program should be planned.

✓ Tailings management:

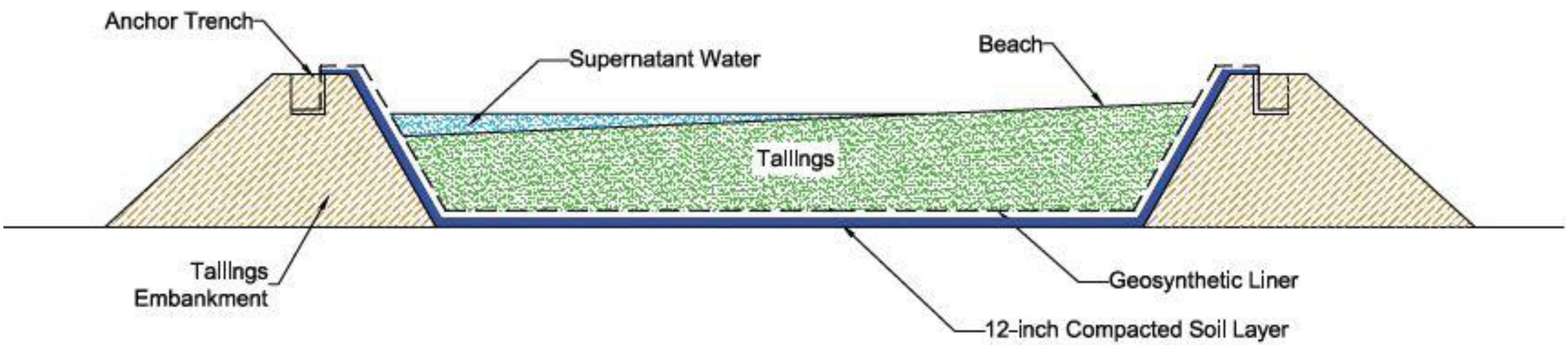
- Tailings, a slurry type fluid usually consisting of crushed rock, chemicals and water, containing low levels of metals
- Typically disposed of in **impoundments**
- Other management practices:
  - disposal in **dry tailings facilities**
  - disposal under water covers (**subaqueous disposal**)

- **Characterization** of the tailings materials is critical to predicting environmental impacts and designing appropriate management

✓ Tailings impoundments

Main characteristics of tailings impoundments:

- Engineered impoundments
- Solid particles settle
- Clarified water from the top is recycled to the process for reuse
- In some cases, water may be discharged from the impoundment → wastewater treatment



Tailings impoundment cross-section
(https://ndep.nv.gov/uploads/land-mining-faq-docs/Tailings_Impoundment.pdf)

✓ Tailings impoundments

Main characteristics of tailings impoundments:

- Engineered impoundments
- Solid particles settle

rocess for reuse

the impoundment

www.nps.gov/articles/aps-v13-i2-c8.htm

www.patersoncooke.com/the-impact-of-ore-body-variability-on-mine-waste-tailings-disposal-systems/

✓ Tailings impoundments

Critical issues related to the design and management of tailing impoundments:

- ✓ Site characterization
- ✓ Impoundments and embankments
- ✓ Liners
- ✓ Tailings water
- ✓ Operational monitoring

✓ Tailings impoundments

Critical issues related to the design and management of tailing impoundments:

✓ **Site characterization**

- ✓ volume of tailings (size of the site)
- ✓ hydrological conditions and climate (underground water, precipitation, runoff, etc.)
- ✓ geologic and geotechnical evaluation (long-term stability, seismic activity, etc.)

✓ Impoundments and embankments

✓ Liners

✓ Tailings water

✓ Operational monitoring

✓ Tailings impoundments

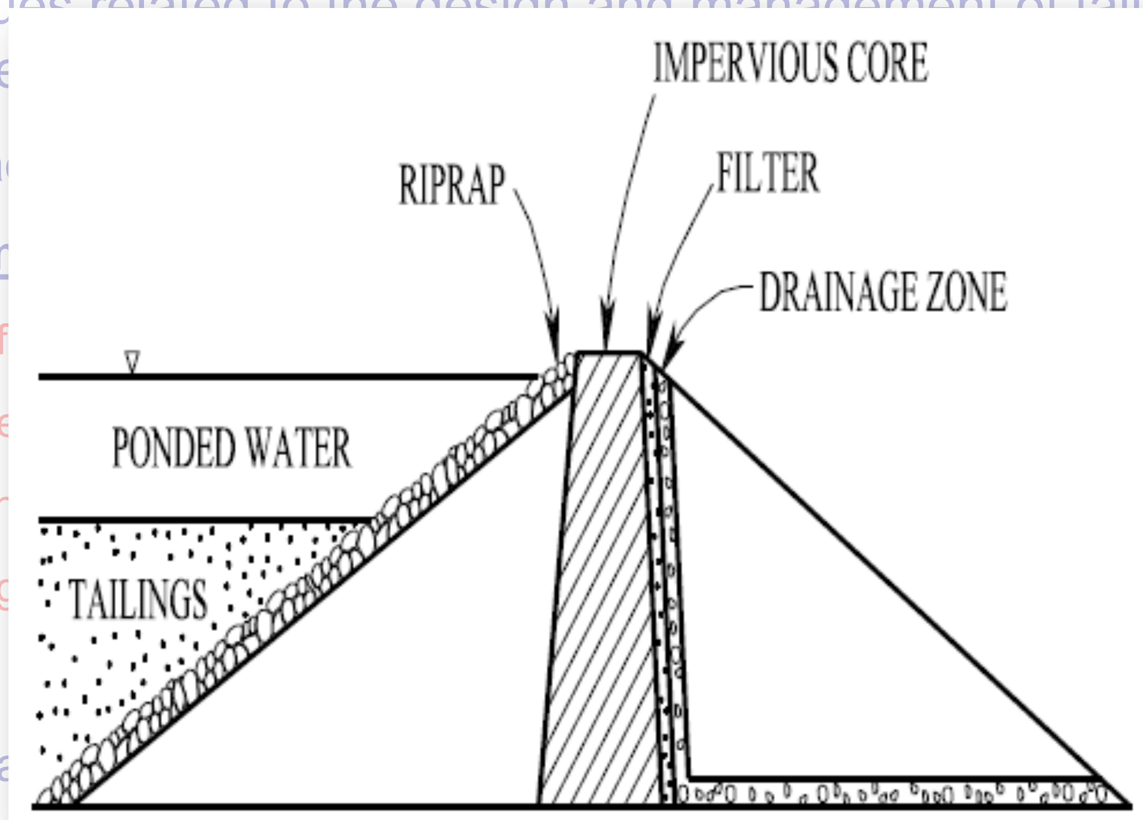
Critical issues related to the design and management of tailing impoundments:

- ✓ Site characterization
- ✓ **Impoundments and embankments**
  - ✓ type of impoundment depending on the site topography
  - ✓ surface embankments: water-retention dams and raised embankments
  - ✓ diverting water around impoundments can be necessary
- ✓ Liners
- ✓ Tailings water
- ✓ Operational monitoring

✓ Tailings impoundments

Critical issues related to the design and management of tailing impoundme

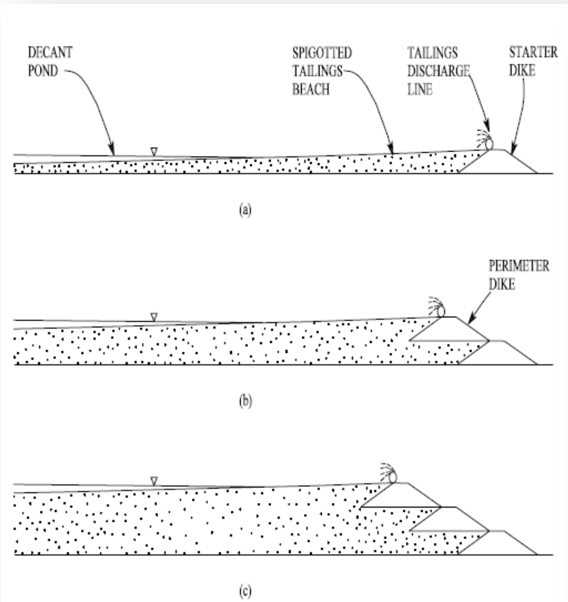
- ✓ Site chara
- ✓ **Impoundr**
  - ✓ type of
  - ✓ surface ... nts
  - ✓ divertir
  - ✓ seepag ... rwise used
- ✓ Liners
- ✓ Tailings wa
- ✓ Operational monitoring

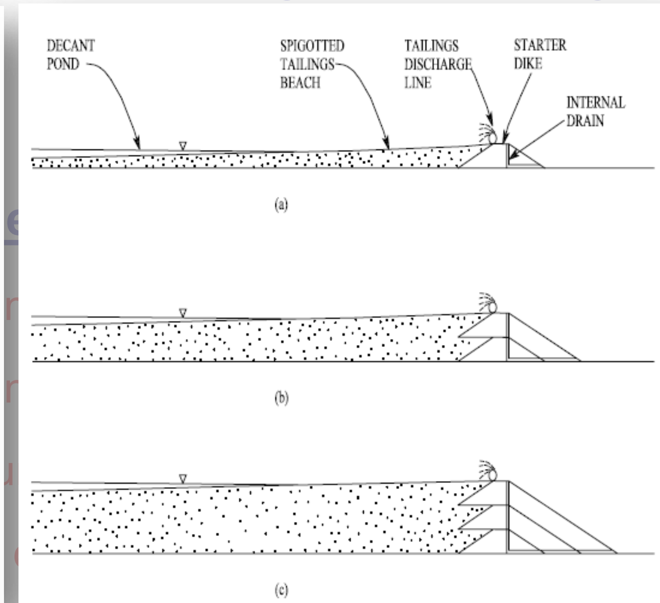


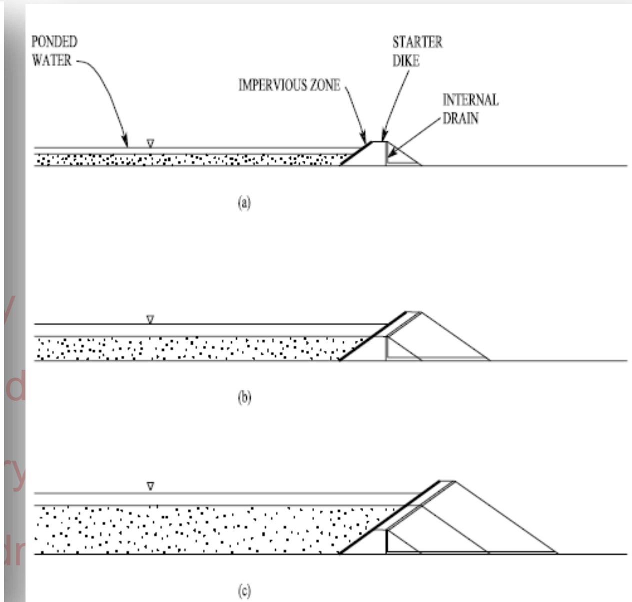
Water-retention type dam for tailings storage

✓ Tailings impoundments

Critical issues related to the design and management of tailing







✓ Liners

Upstream, centerline and downstream raised embankments

✓ Tailings water

✓ Operational monitoring

✓ Tailings impoundments

Critical issues related to the design and management of tailings impoundments:

- ✓ Site characterization
- ✓ Impoundments and embankments
- ✓ **Liners**
  - ✓ where process effluents contain toxic constituents (cyanide, metals, etc.) and there is a risk to ground water → impermeable layer at the bottom
  - ✓ tailings pond liner: compacted clay or geosynthetic materials
- ✓ Tailings water
- ✓ Operational monitoring

✓ Tailings impoundments

Critical issues related to the design and management of tailing impoundments:

- ✓ Site characterization
- ✓ Impoundments and embankments
- ✓ Liners
- ✓ **Tailings water**
  - ✓ may contain high metals concentrations, process chemicals, acidity, etc.
  - ✓ could be reused for mineral and metal processing
  - ✓ could be discharged, after an appropriate treatment
- ✓ Operational monitoring

✓ Tailings impoundments

Critical issues related to the design and management of tailing impoundments:

✓ Site characterization

✓ Impoundments and embankments

✓ Liners

✓ Tailings water

✓ **Operational monitoring**

- ✓ monitoring plans should be provided
- ✓ focused on detecting changes in: embankment stability, surface and ground water quality, ground water flowrate, and air quality

✓ Dry tailings facilities

✓ Relatively new method

✓ Tailings are dewatered using thickeners, belt filters and filter presses, and then:

→ dry tailings are placed in dumps, compacted and covered

→ water is reused for mining operation

Main advantages	Main disadvantages
Reduces the potential for surface and ground water contamination	High unit costs
Ability to reclaim more process water	Difficulty in placing materials in wet climates

✓ Subaqueous tailings disposal

✓ Far less common than tailing ponds

✓ A water cover is maintained over the tailings to control oxidation of sulphides and subsequent acid generation

✓ Carried out by depositing mine tailings directly into a body of water:

→ engineered impoundments

→ flooded mines

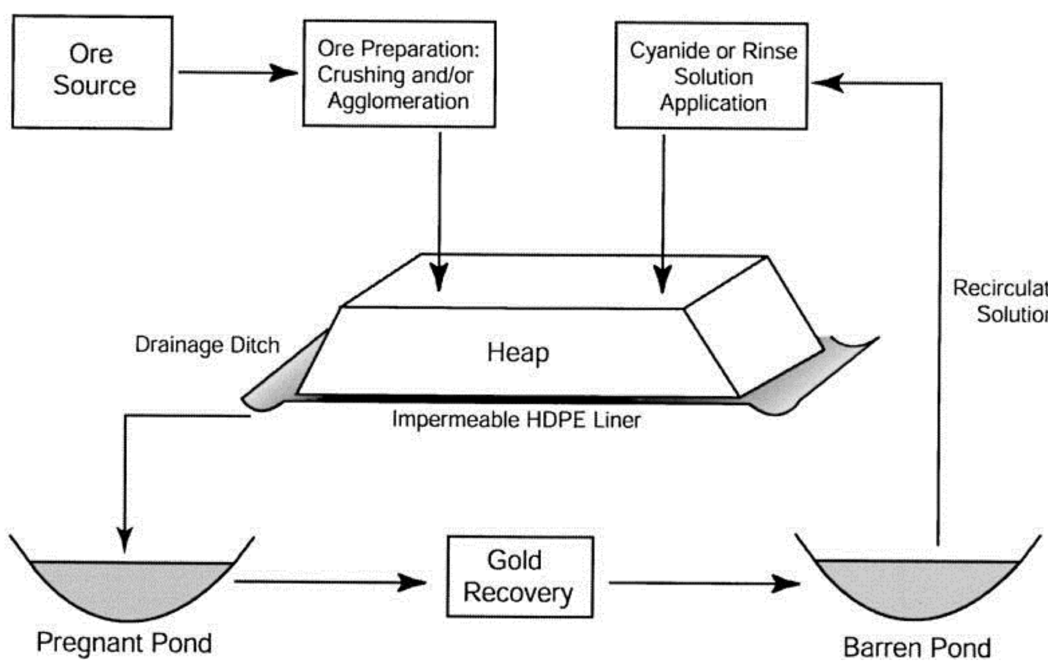
Main advantages	Main disadvantages
Control acid generation by limiting available oxygen for oxidation process	Need of perpetual maintenance to ensure a permanent water cover
Eliminating surface erosion and dust caused by wind and water action	Water supply to maintain a minimum water depth
Lower implementation costs compared to the costs of a soil cover	Higher potential for embankment failure due to seismic events or erosion

✓ Spent ore/heap and dump leach management:

✓ Two main **types** of heap leach facilities:

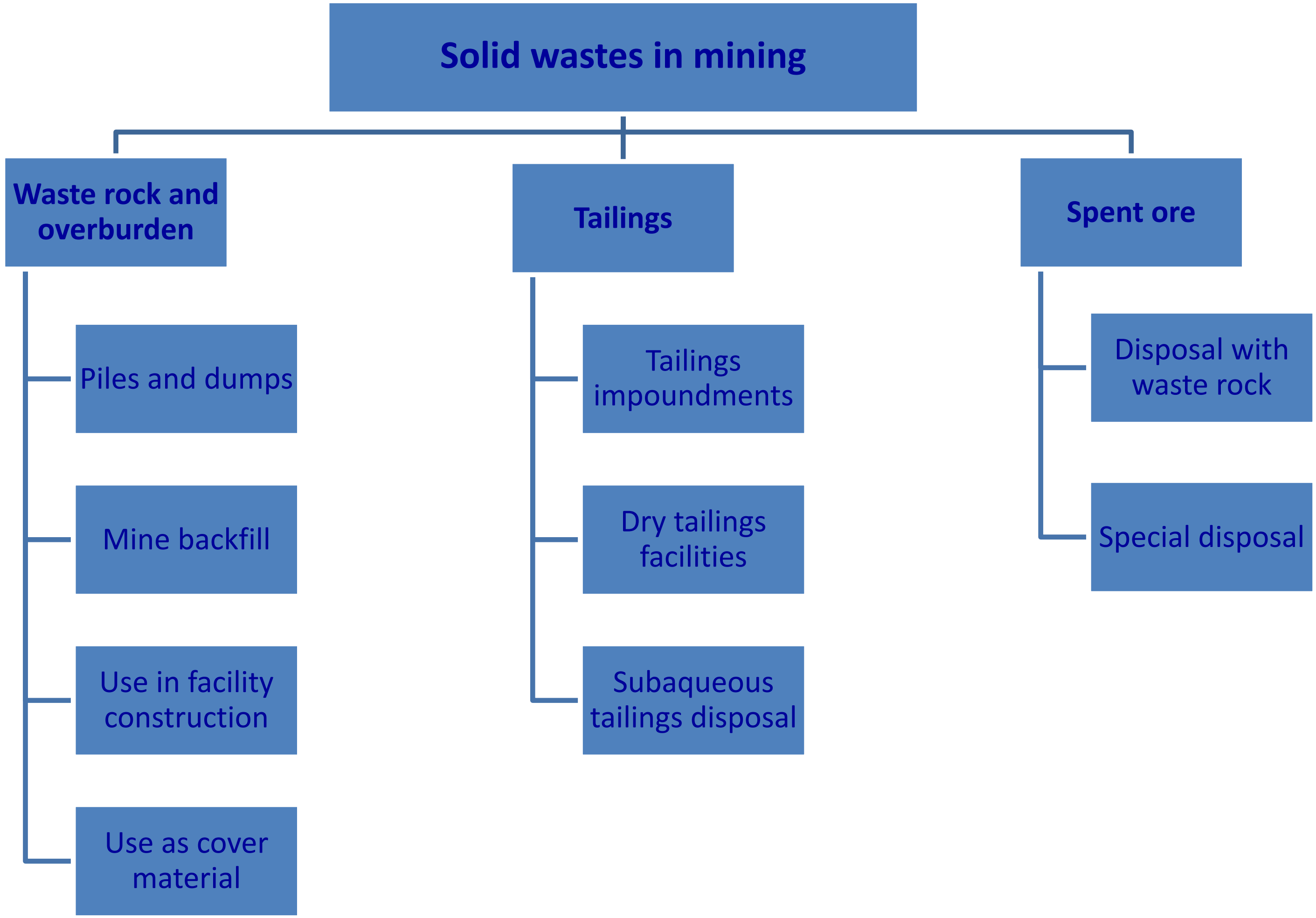
✓ **Reusable heaps or pads (“on-off” pads).** Spent ore is removed and transported to a separate disposal facility at the end of the leach cycle. Fresh ore is replaced on the pad for a new leach cycle.

✓ **Dedicated or permanent heaps/pads.** For a single use, with spent ore remaining in place at the end of the leach cycle. Fresh ore is placed on newly constructed pad.



✓ Spent ore/heap and dump leach management:

- ✓ Two main **types** of heap leach facilities:
  - ✓ **Reusable pads ("on-off" pads).** Spent ore is removed and transported to a separate disposal facility at the end of the leach cycle. Fresh ore is replaced on the pad for a new leach cycle.
  - ✓ **Dedicated or permanent pads.** For a single use, with spent ore remaining in place at the end of the leach cycle. Fresh ore is placed on newly constructed pad.
- ✓ Spent ore management and disposal:
  - ✓ Impermeable **liners** underneath leach pads to prevent leaching agents to degrade surface and ground waters
  - ✓ Criteria for choosing the **location**, similar to those for waste rock dumps and tailings impoundments
  - ✓ The **manner of management** of spent ore will depend on the likelihood of contaminating surface or ground waters:
  - ✓ Unlikely to have deleterious effects → disposal with waste rock materials
  - ✓ Expected to contribute to poor water quality → special disposal


Solid wastes in mining
Waste rock and overburden
Tailings
Spent ore
Piles and dumps
Mine backfill
Use in facility construction
Use as cover material
Tailings impoundments
Dry tailings facilities
Subaqueous tailings disposal
Disposal with waste rock
Special disposal

- **Types of solid wastes in mining**: overburden, waste rock, tailings, and spent ore (definition and potential pollution)
- **Waste rock and overburden management**: piles and dumps, mine backfill, use in facility construction, and use as cover materials (main characteristics of each one)
- **Piles and dumps**: when are they used?, identification of the main processes happening in a waste rock pile or dump
- **Tailings management**: impoundments (description, characteristics and design), dry tailings facilities and subaqueous disposal (main characteristics, advantages and disadvantages, when is it worth to use each one?)
- **Spent ore from leaching**: management and disposal

Glossary of mining terms:
https://www.sec.gov/Archives/edgar/data/1165780/000116578003000001/glossary.htm#O

www.youtube.com/watch?v=UxF9l6bedZU

Environmental impact of mining:

- Major categories of impacts
  - ✓ Disturbances to the earth
  - ✓ Solid waste
  - ✓ Air pollution
  - ✓ Water pollution
- Legislation
  - ✓ Directive 2006/21/EC, Royal Decree 975/2009

Chapter 3.3. Mining and the environment:

(1) Wastewater and waste materials in mining

(1.1) Wastewater sources, management and treatment

(1.2) Waste materials, types and management

(2) Environmental impact of mining

(2.1) Major categories of impacts

(2.2) Legislation

► Disturbances to the earth:

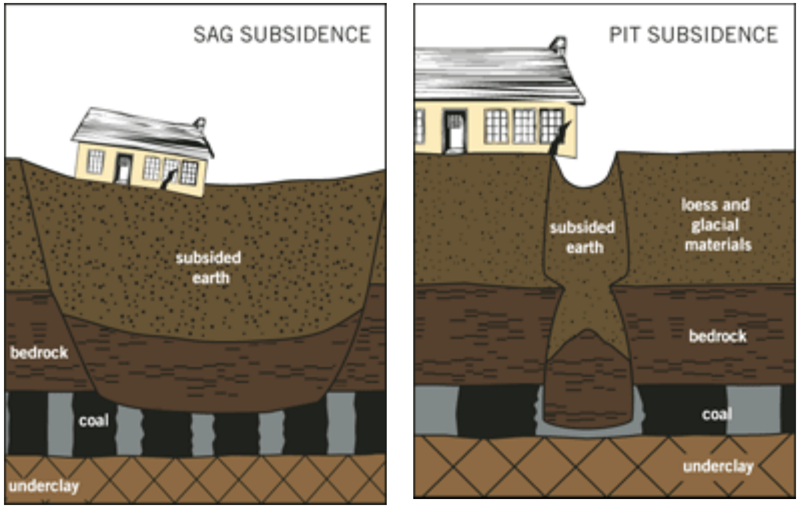
✓ Slope failure: stability of open pit slope, landslip

✓ Subsidence and sink holes: movement of the surface resulting from the collapse of overlying strata into mine voids

✓ Earth tremors

✓ Collapse (underground fires)

Bingham Canyon Mine (Utah, USA) landslip, 2013



Subsidence and sink holes

Bingham Canyon mine (Utah, USA): landslip (2013)

Bingham Canyon landslip was expected

Bingham Landslide

► Solid waste:

✓ Waste rock and overburden. Impact to the landscape, and the solid material interacts with water and air.

✓ Mine tailings. Water infiltration (leakage), and risk of tailing dam failure.

Waste rock dump

Tailings impoundment

Aznalcóllar disaster: tailings impoundment dam failure (April 1998)

La catástrofe ambiental de Aznalcóllar (Canal Sur Televisión, 1996-98)

20 años del desastre de Aznalcóllar (El País)

Mina de Azalcóllar. 20 años después (Los Reporteros CS)

► Air pollution:

- ✓ Gases from the underground works and fires
- ✓ Dust from the waste rock dumps and dry tailings
- ✓ Other chemical compounds: cyanide (extremely toxic), asbestos (asbestosis and cancer), radioactivity (from uranium and others)

Dust from mine tailings or waste rock dumps

▶ Water pollution:

✓ Acidic mine drainage (sulphide+oxygen+water, affects aquatic ecosystems, damages the quality of surface and ground water)

✓ Heavy metals (dissolved at low pH, are toxic, bioaccumulation)

✓ Sedimentation (erosion and detachment from solid materials, transport and deposited in nearby streams)

✓ Other chemical compounds: cyanide (extremely toxic)

✓ Radioactivity (from uranium and others)

Acidic mine drainage with heavy metals dissolved in water

- Strategies for reducing environmental impacts of mining (among others):
  - ✓ Prevent or reduce the generation of waste
  - ✓ Backfilling the mine voids with waste rock
  - ✓ Spraying with water to reduce dust
  - ✓ Covering with vegetation the waste rock dumps and dry tailings
  - ✓ Tailing impoundments well designed to avoid any water to escape: channels, dams, liners, etc.
  - ✓ Treatment of wastewater: neutralization, metals precipitation, constructed wetlands, etc.
  - ✓ Removal of dams and construction of new tailings impoundments
  - ✓ Monitoring dam stability, water quality, air pollution, etc.

Chapter 3.3. Mining and the environment:

(1) Wastewater and waste materials in mining

(1.1) Wastewater sources, management and treatment

(1.2) Waste materials, types and management

(2) Environmental impact of mining

(2.1) Major categories of impacts

(2.2) Legislation

- Europe:

Directive 2006/21/EC, on the **management of waste from extractive industries**

- Spain:

Royal Decree 975/2009, of 12th June, on the **waste management of extractive industries and on the protection and rehabilitation of the space affected by mining activities** (modif. RD 777/2012)

Royal Decree 975/2009

- Object

The present Royal Decree aims at the establishment of measures, procedures and guidance to **prevent or reduce** as far as possible **the adverse effects on the environment**, in particular on water, air, soil, fauna, flora and landscape, **and the risks to human health** that may be **produced by research and exploitation of mineral deposits** and other geological resources, and, fundamentally, the management of mining waste.

Royal Decree 975/2009

- Main requirements

(1) Extractive waste should be managed without endangering human health and without using processes or methods which could harm the environment.

(2) It is prohibited the abandonment, dumping or uncontrolled deposit of extractive waste.

(3) Operators should take measures to manage extractive waste preventing or reducing adverse effects on the environment and human health, also after closure, and to prevent major accidents.

Royal Decree 975/2009

Restoration plan

The operator should prepare a restoration plan including:

(a) Description of the environment

(b) Measures for the rehabilitation of the natural space

(c) Measures for the rehabilitation of the facilities and services attached to the research and exploitation

(d) Waste management plan

(e) Time schedule and budget

Waste management plan

The operator should prepare a waste management plan in order to:

(a) Prevent or reduce waste production and its harmfulness

(b) Encourage the recovery of extractive waste by means of recycling, reusing or reclaiming such waste

(c) Ensure short and long-term safe disposal of the extractive waste, in particular by considering, during the design phase, management during the operation and after-closure

- **Major categories of impacts:** Disturbances to the earth; Solid waste; Air pollution; Water pollution. Examples and description
- **Strategies for reducing environmental impacts of mining:** Examples
- **Legislation:** Objective, requirements, restoration plans, waste management plans

Links to videos:

Environmental Impact of Mining: www.youtube.com/watch?v=UxF9l6bedZU

Bingham Canyon mine landslide was expected: https://www.youtube.com/watch?v=tSmhU2OEw7A&t=1s

Bingham Landslide: https://www.youtube.com/watch?v=-qRfYe90aBc

La catástrofe ambiental de Aznalcóllar: https://www.youtube.com/watch?v=jqWFe2bTkcs

20 años del desastre de Aznalcóllar: https://www.youtube.com/watch?v=rvO0pIakyF8

Mina de Azalcóllar. 20 años después: https://www.youtube.com/watch?v=BvPNxMdTx8U

Glossary of mining terms:
https://www.sec.gov/Archives/edgar/data/1165780/000116578003000001/glossary.htm#O