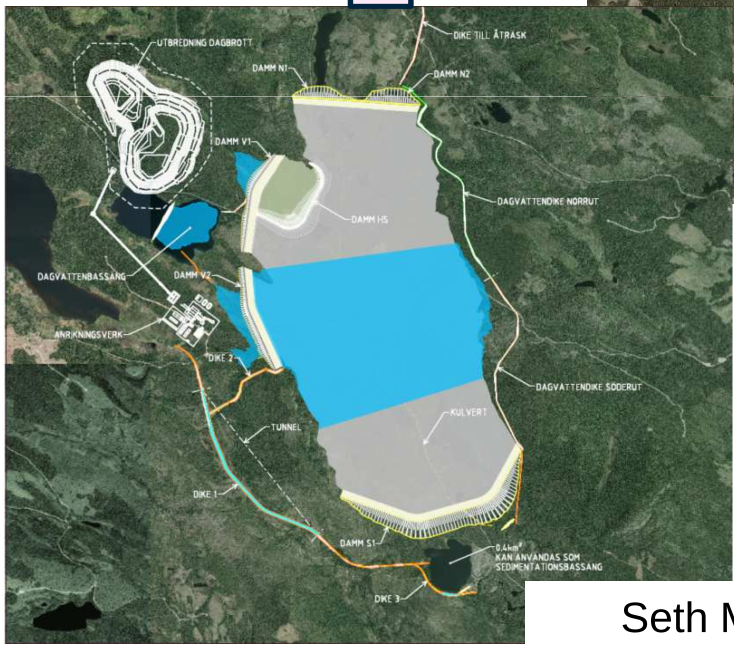
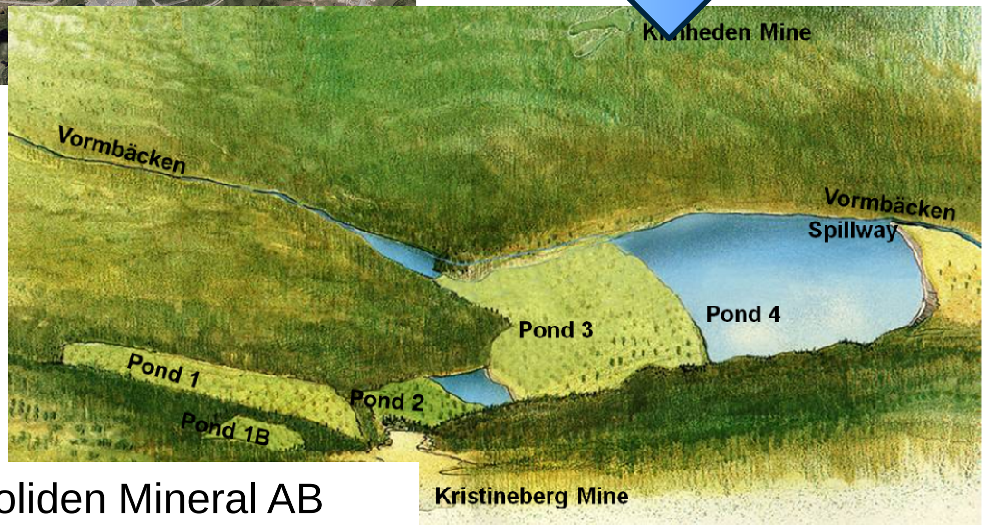
# Mine Water Management
# -From Pre-feasibility to Closure




Seth Mueller, Boliden Mineral AB
Mine Water Management and Treatment
Kuopio, Finland 2013-09-24

NEW BOLIDEN

# Outline

- Water managment plan approach
- Water balance models as a tool for planning and management
- Pre-feasibility- Laver example
- Under operations- Aitik example
- Closure Planning

NEW BOLIDEN

# Water Management Plan Approach

- Define objectives
- Define exisiting conditions
- Develop water balance models
- Identify and implement optimization measures
- Identify and minimize risks
- Water management plan/reporting internal control/ Annual Report

# Model Construction

- GoldSim (www.goldsim.com)

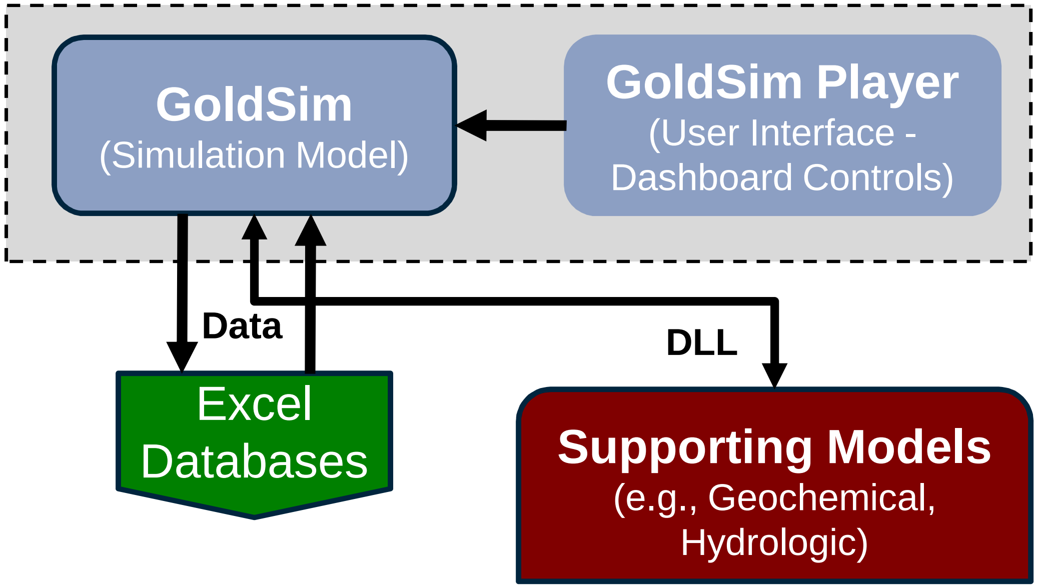
- **Reasons**
- Commonly used for mine and environmental application (large user group)
- Visual development environment with a large number of modeling “elements” including logical and discrete event capabilities
- Strong probabilistic capabilities
- Hierarchical structure
- Integration with Excel and relational databases
- Chemistry capabilities
- Sensitivity and optimization tools
- GoldSim Player dashboard models can be used license-free
- Number of different modules for different types of models

NEW BOLIDEN

# What is Goldsim?

## Framework for developing deterministic and probabilistic simulation models

- Water
- Chemistry
- Work-flow
- Decision support
- Reliability
- Risk assessment
- Economics
- Etc.




DLL=Dynamic Link Library

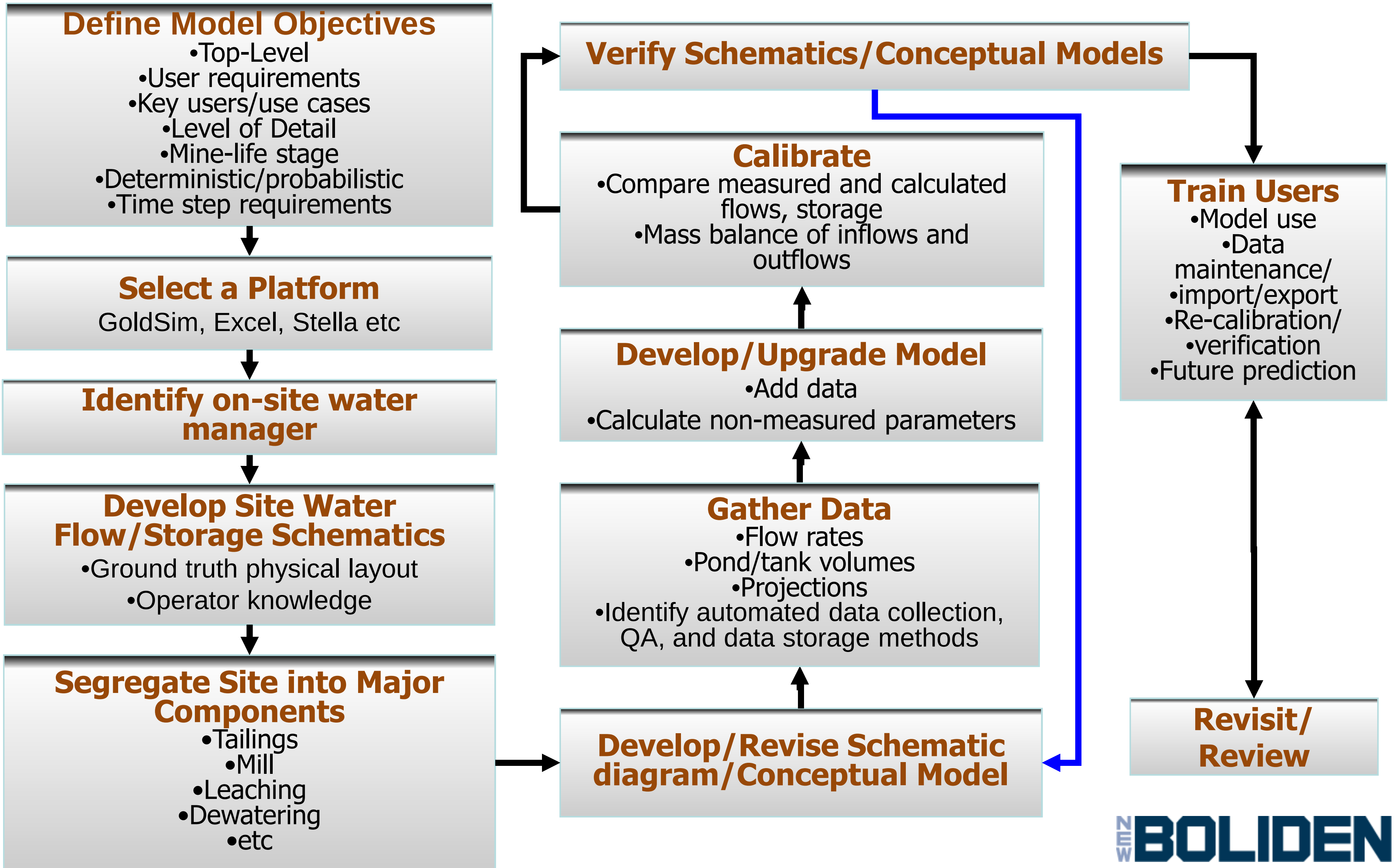
# Input data types

- **Static Data**
- Physical data such as: catchment areas, max and min volumes, stage-volume relationships, etc.

- **Real-Time Pre-Operational and Operational data**
- Measured data such as: historical precipitation, flow meter records, mine production, slurry flow and density, etc.

- **Dynamic and Uncertain Data**
- Projected data or calculated such as: future precipitation, future mine production, seepage rates, heap draindown, etc.

# Model Development



# Model development

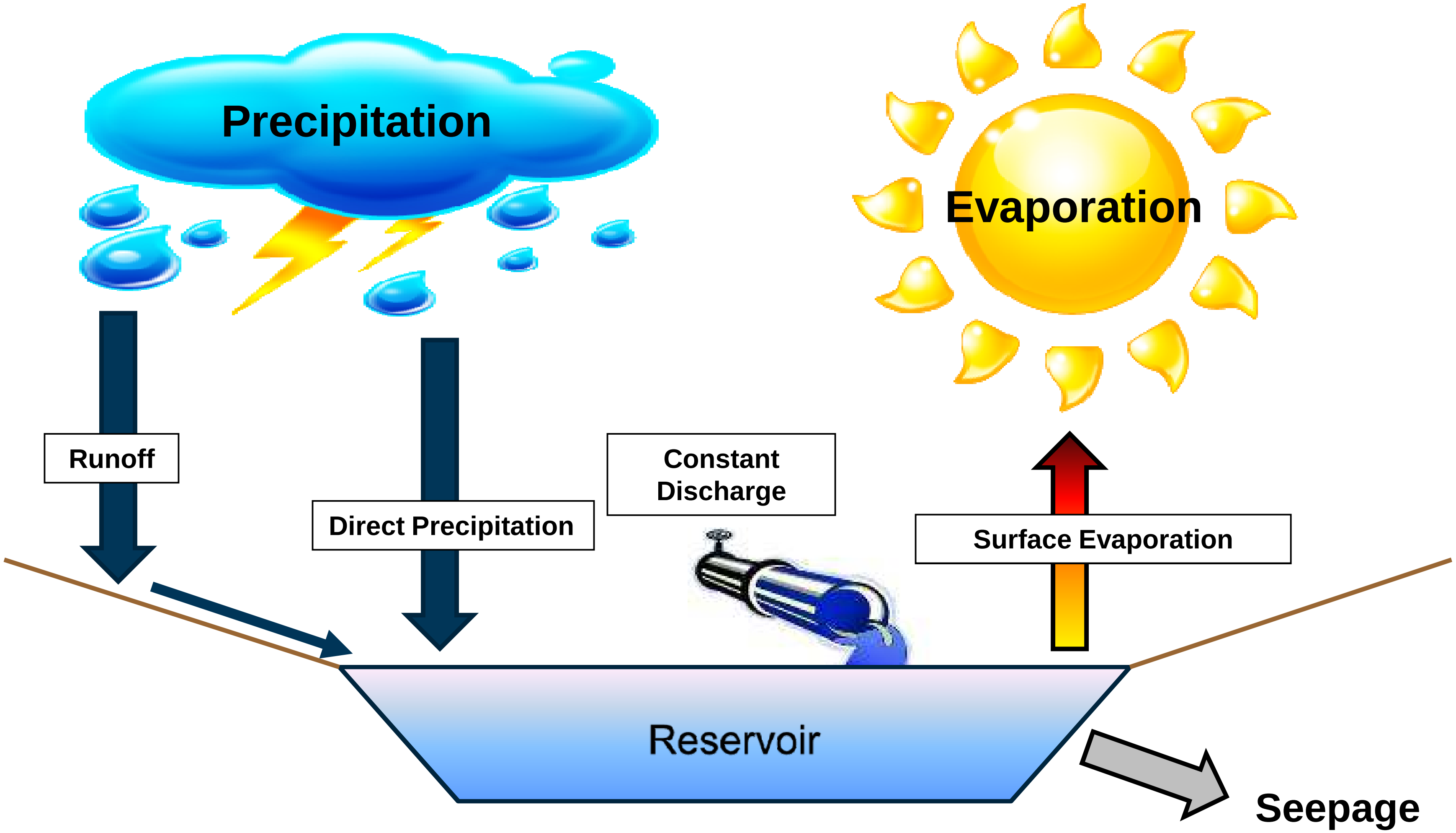
- **The conceptual model is the key to building a useful water balance model**

- **Conceptual model development is a step-wise process:**

1. High level conceptualization based on facility arrangement and flow connections between facilities (schematics, flow sheets engineering designs, aerial photos, maps, previous water balances, examine physical layouts against schematics, etc.)
2. Consider primary purposes of model
3. Develop water balance submodels for facilities
4. Identify sources of measured data
5. Formulate approaches for non-measured data
6. Construct and test model
7. Iterate where conceptualizations need revision

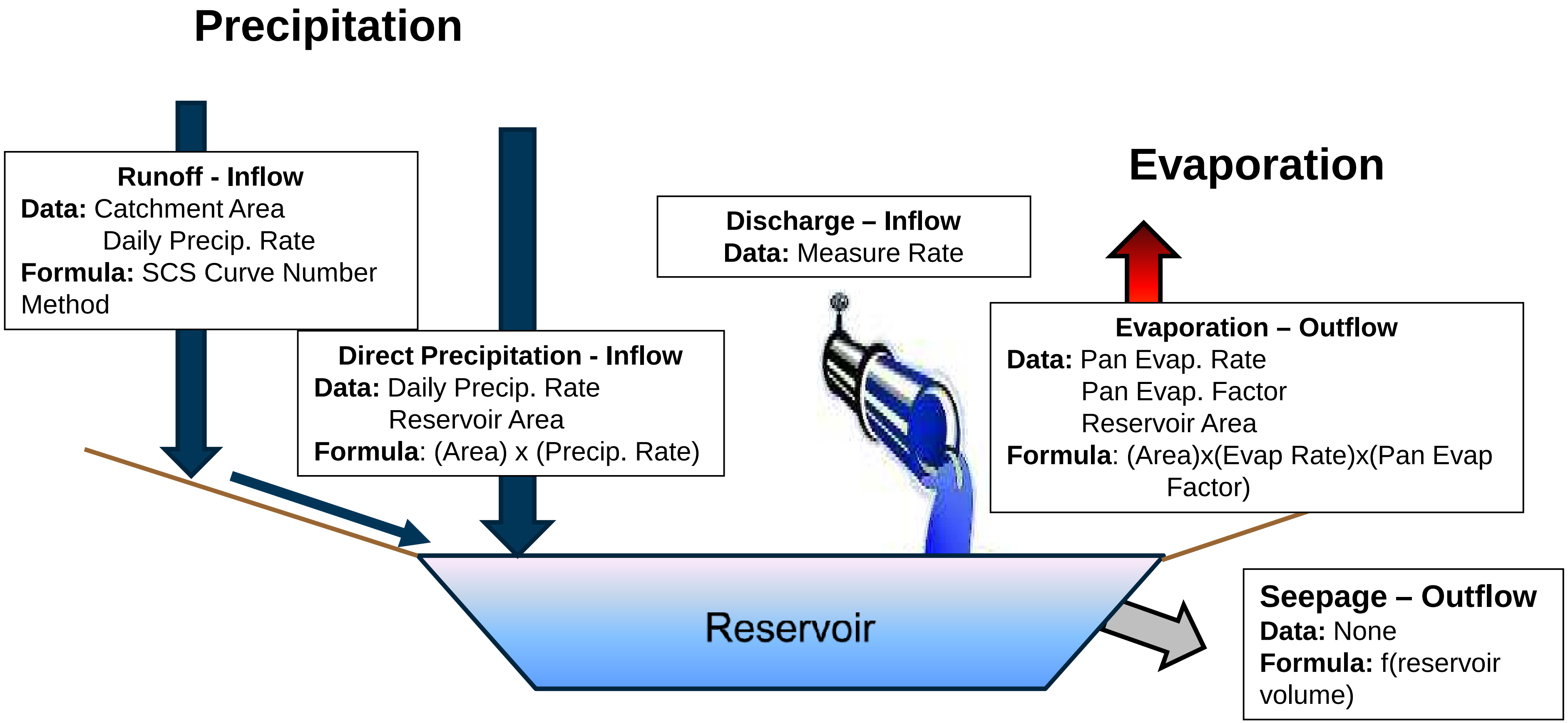
NEW BOLIDEN

# Model development: High level conceptual model



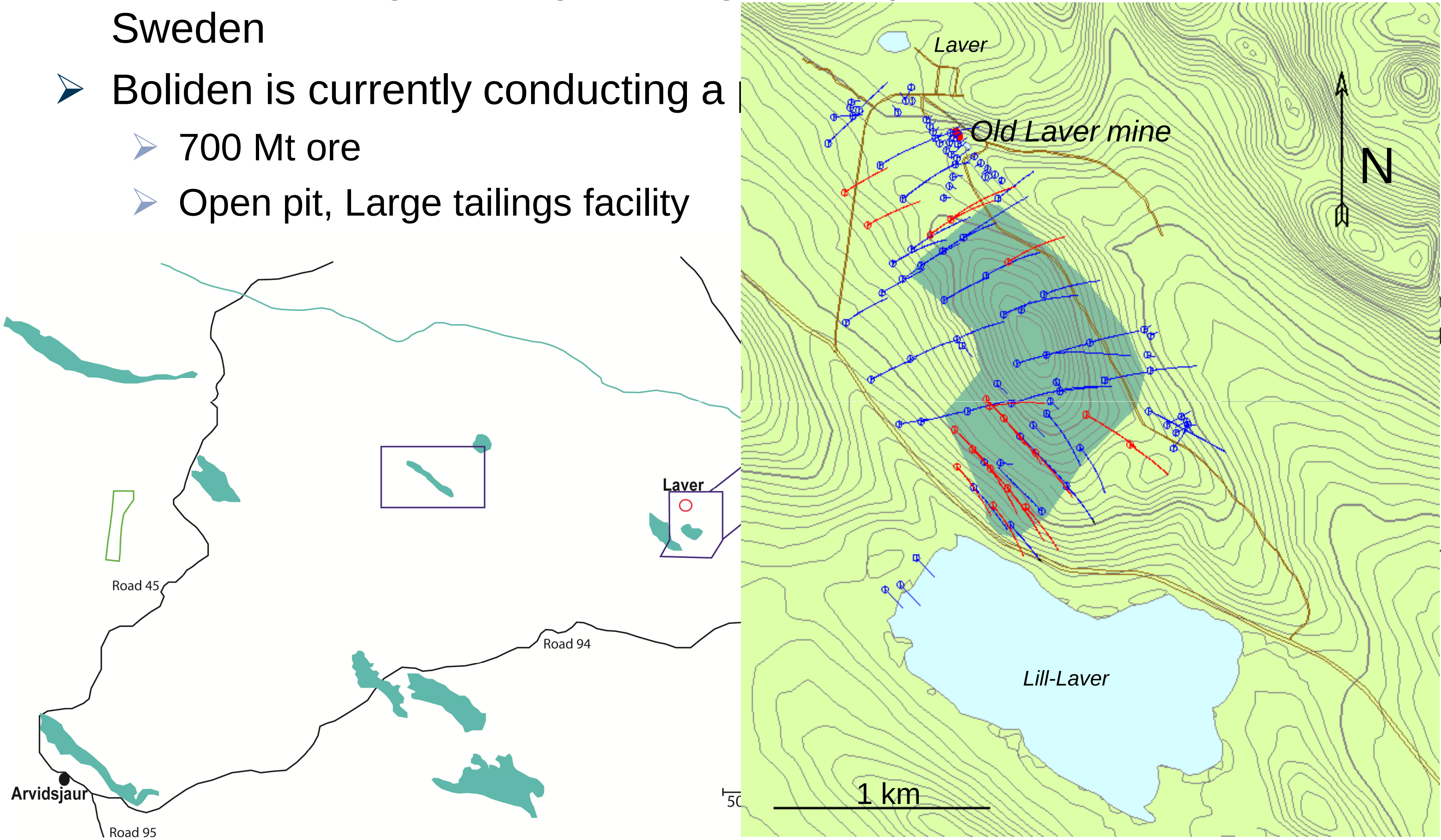

NEW BOLIDEN

# Conceptual Model: Add detail



# Pre-feasibility-Laver

- Laver is a low grade, high tonnage Cu deposit located in northern Sweden
- Boliden is currently conducting a
  - 700 Mt ore
  - Open pit, Large tailings facility




Exploration permits, Boliden Mineral AB
Exploration permits, Other company

BOLIDEN

# Pre-feasibility-Laver: *Objectives*

*Often dictated by permit requirements and mine requirements……*

**Regulatory:**

- Pre-mining conditions
- Potential impacts to flow regime
- Potential impacts to water quality
- Discharge flow and quality
- Extreme climate events
- Water use
- Plan to minimize potential impacts

**Mine Planning/Water Management:**

- Pre-mining conditions
- Water demand
- Water storage
- Water recycling
- Water separation (contact v. non-contact)
- Discharge flow and quality
- Extreme climate events
- Plan to minimize potential impacts

NEW BOLIDEN

# Pre-feasibility: *Model Development*

**Define Model Objectives**
- Top-Level
- User requirements
- Key users/use cases
- Level of Detail
- Mine-life stage
- Deterministic/probabilistic
- Time step requirements

**Select a Platform**

GoldSim, Excel, Stella etc

**Identify on-site water manager**

**Develop Site Water Flow/Storage Schematics**
- Ground truth physical layout
- Operator knowledge

**Segregate Site into Major Components**
- Tailings
- Mill
- Leaching
- Dewatering
- etc

**Develop/Revise Schematic diagram/Conceptual Model**

**Gather Data**
- Flow rates
- Pond/tank volumes
- Projections
- Identify automated data collection, QA, and data storage methods

**Develop/Upgrade Model**
- Add data
- Calculate non-measured parameters

**Calibrate**
- Compare measured and calculated flows, storage
- Mass balance of inflows and outflows

**Verify Schematics/Conceptual Models**

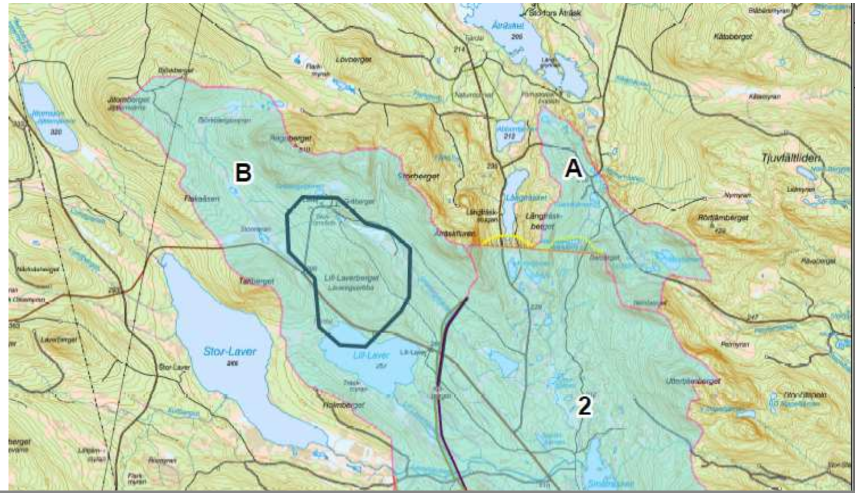
**Train Users**
- Model use
- Data maintenance/
- import/export
- Re-calibration/
- verification
- Future prediction

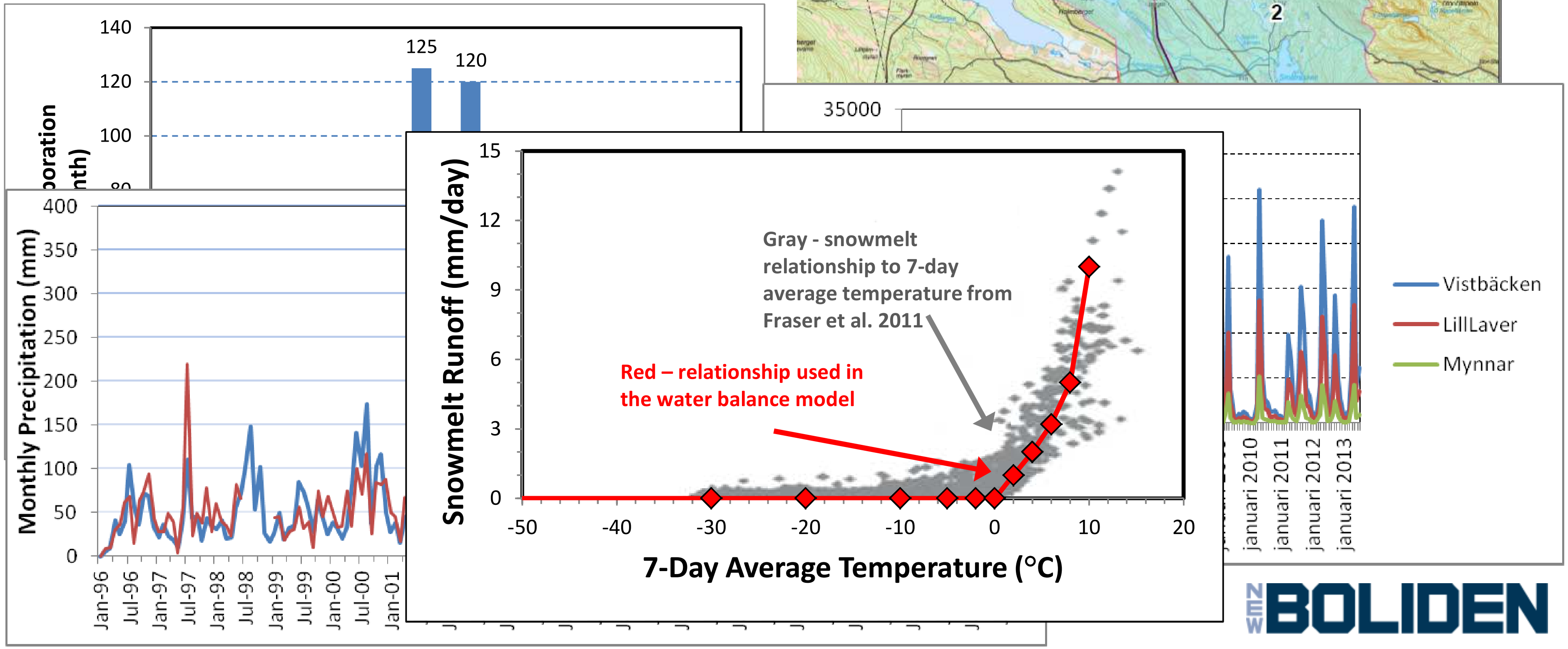
**Revisit/ Review**

# Pre-feasibility:*Existing Conditions*

## Background Data

- Drainage basins
- Natural water flow/chemistry
- Climate data
- Preliminary groundwater assessments
- Environmental data




NEW BOLIDEN

# Pre-feasibility: *Additional data*

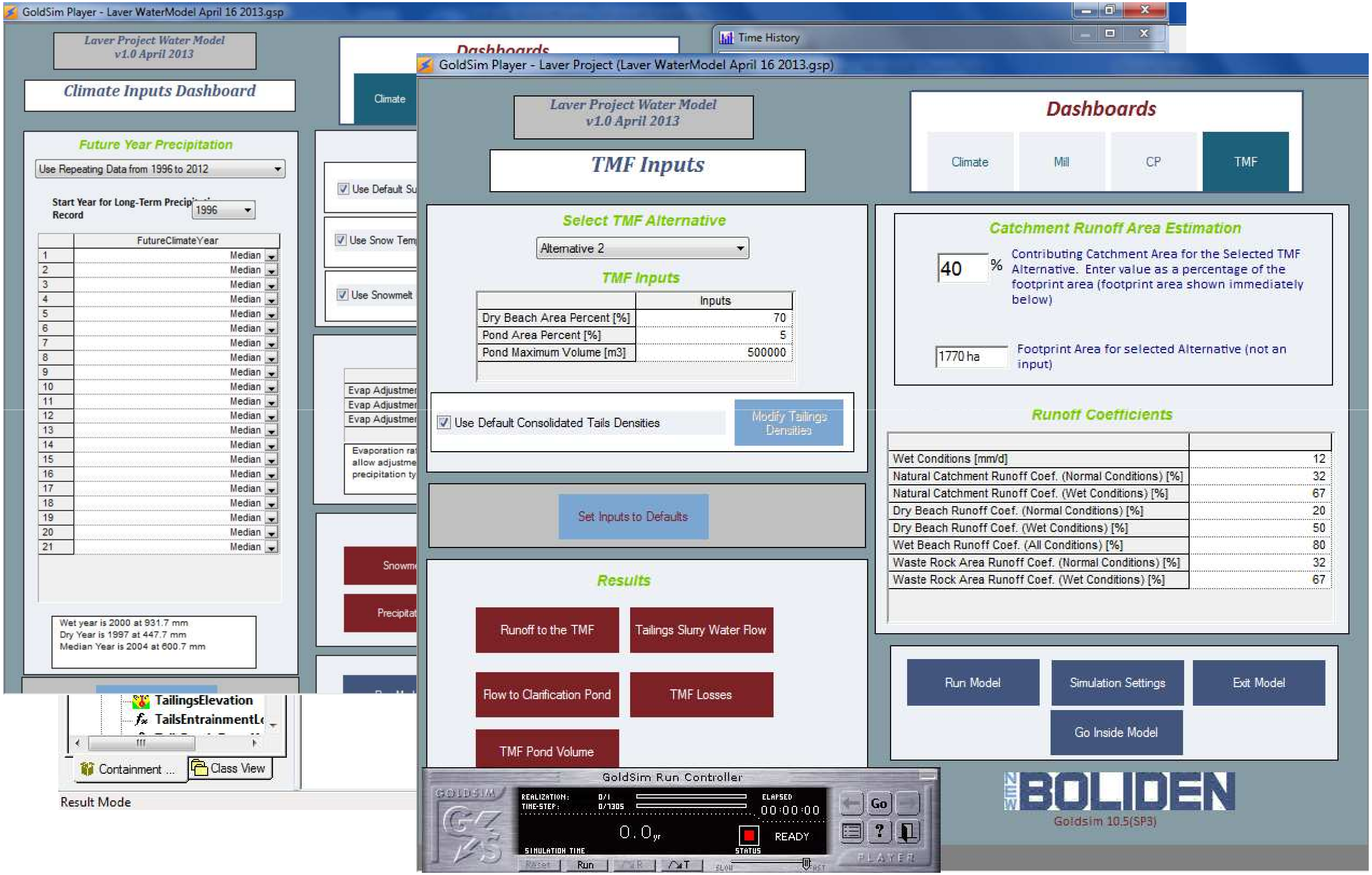
- Mine plan
- Estimated mill water requirements, paramenters
- Tailings void water loss
- Storage pond/tank volumes
- etc

| Year | Pit Depth (m) | Dewater Rate ($m^3/d$) |
|---|---|---|
| 0 | 0 | 270 |
| 1 | 25 | 559 |
| 2 | 50 | 878 |
| 3 | 75 | 1227 |
| 5 | 100 | 1607 |
| 10 | 200 | 3426 |
| 15 | 300 | 5726 |
| 18 | 400 | 8509 |

| Parameter | Units | Value | Source |
|---|---|---|---|
| Mine Life | years | 20 | Production schedule from Boliden |
| Process Slurry Percent Solids | % | 40 | Estimated based on discussions with Boliden staff |
| Process Slurry Daily Variation in Percent Solids | % | ± 5 | Estimated based on observations at other mines |
| Ore Moisture Content | % | 2 | Estimate from Boliden |
| Ore Production Rate | tonne/d | See Table 4 | Estimate from Boliden |
| Ore Production Rate Daily Variability | % | ± 15 | Production schedule from Boliden |
| Maintenance Shutdown | NA | 1 day per 16 days operation | 8200 hours production per year; 8760 hours in year |
| Flow Rate in Tailings Line on Days Mill is shutdown | $m^3/hr$ | 500 | Estimated |
| Tailings Thickening | % | 0 or 40-60 | Estimated from Aitik expansion feasibility |

NEW BOLIDEN

# Pre-feasibility: *The model*



# Pre-feasibility-Laver: *How are we using the model*

- Optimize storage volumes
- Pump Capacity
- Climate scenarios
- Building in chemistry-internal water quality/discharge water quality
- Water use (groundwater and surface water)/downstream impacts
- Tailings deposition and water management

- It will be a critical tool in the permitting process

# Aitik: *Operations Water Management*

- One of Europe's largest copper mines.
- Aitik pit is 3 km long, 1.1 km wide and 450 meters deep.
- Salmijärvi Pit will be 1 km long, 800 m wide and 270 meters deep.
- The deposit consists of chalcopyrite containing copper, gold and silver.
- Production 2012, 34 Mt.
- Tailings facility  ca 9 $km^2$


# Aitik: *Building a water managment plan*

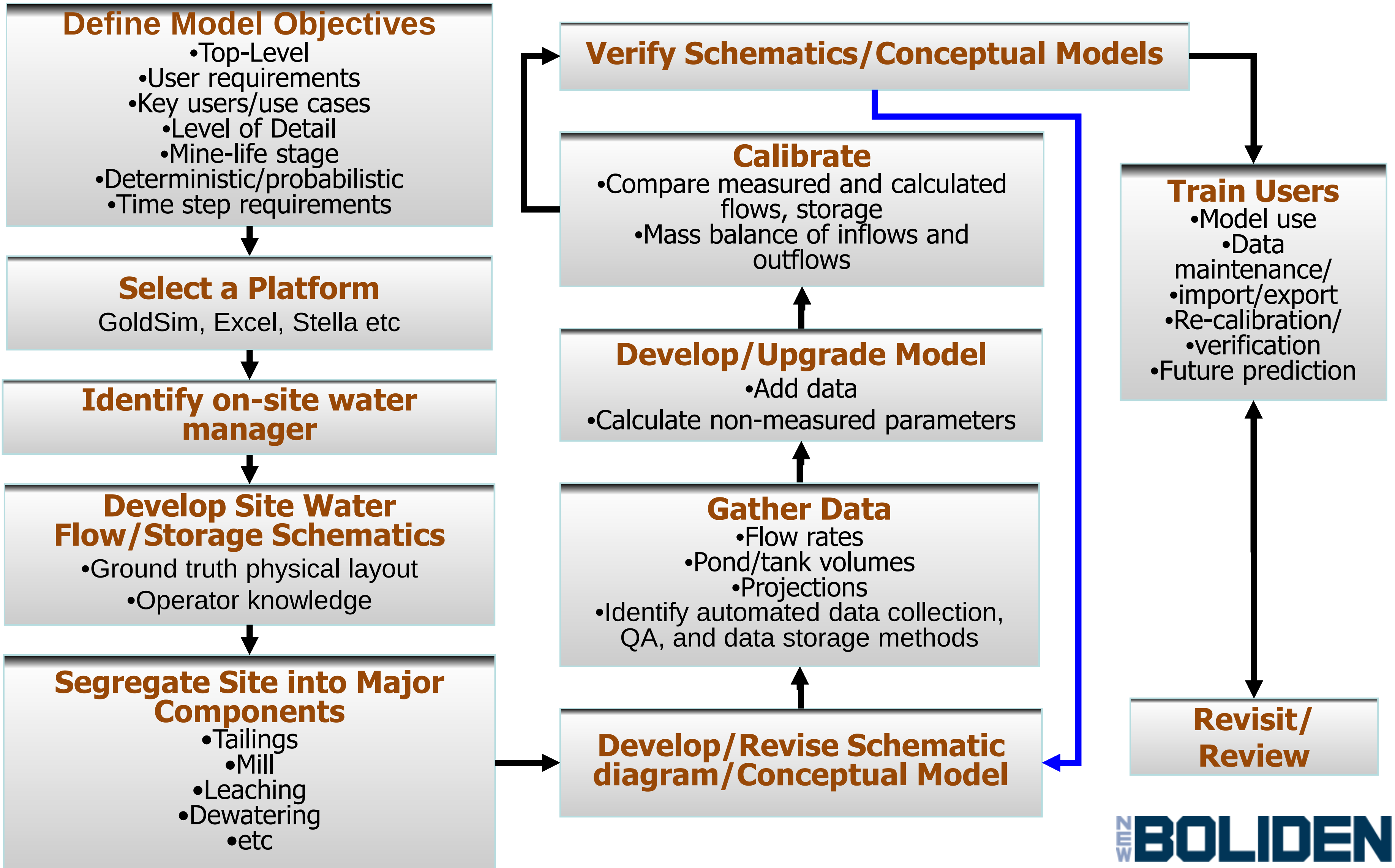
- Water storage capacity
  - Storm events (snow melt, rain)
- Optimization of mine water
  - Increased efficiency use
  - Water use/recycling
- Discharge water
  - New demands from regulators
  - Water treatment?
- Pumping
  - Building in redundancy
  - Evaluating failure scenarios
- Expansions/Changes
  - Tailings facility
  - Increased Production

NEW BOLIDEN


DIKESINVENTERING
UNDERLAG:
TERRÄNGMODELL FRÅN FLYGNINGAR UTFÖRDA 2008 OCH 2010 SAMT 2010-ÅRS ORTOFOTO
TRE DAGARS INVENTERING I FÄLT FÖR VERIFIERING AV AKTUELLT LÄGE MED HJÄLP AV ORTOFOTO FRÅN 2010
UTIFRÅN OVANSTÅENDE HAR EN CAD-MODELL KONSTUERATS SOM VISAR IDENTIFIERADE DIKENS LÄGE.
I MODELLEN SKILJS NATURLIGA OCH KONSTUREADE DIKEN
KONSTRUERADE DIKEN
NATURLIGA SJÖAR OCH VATTENDRAG
DAGBROTTET
ÅTERVINNINGS-BASSÄNG
KLARNINGSMAGASIN
SANDMAGASIN
SALMIJÄRVI
NYA VERKET

NEW BOLIDEN

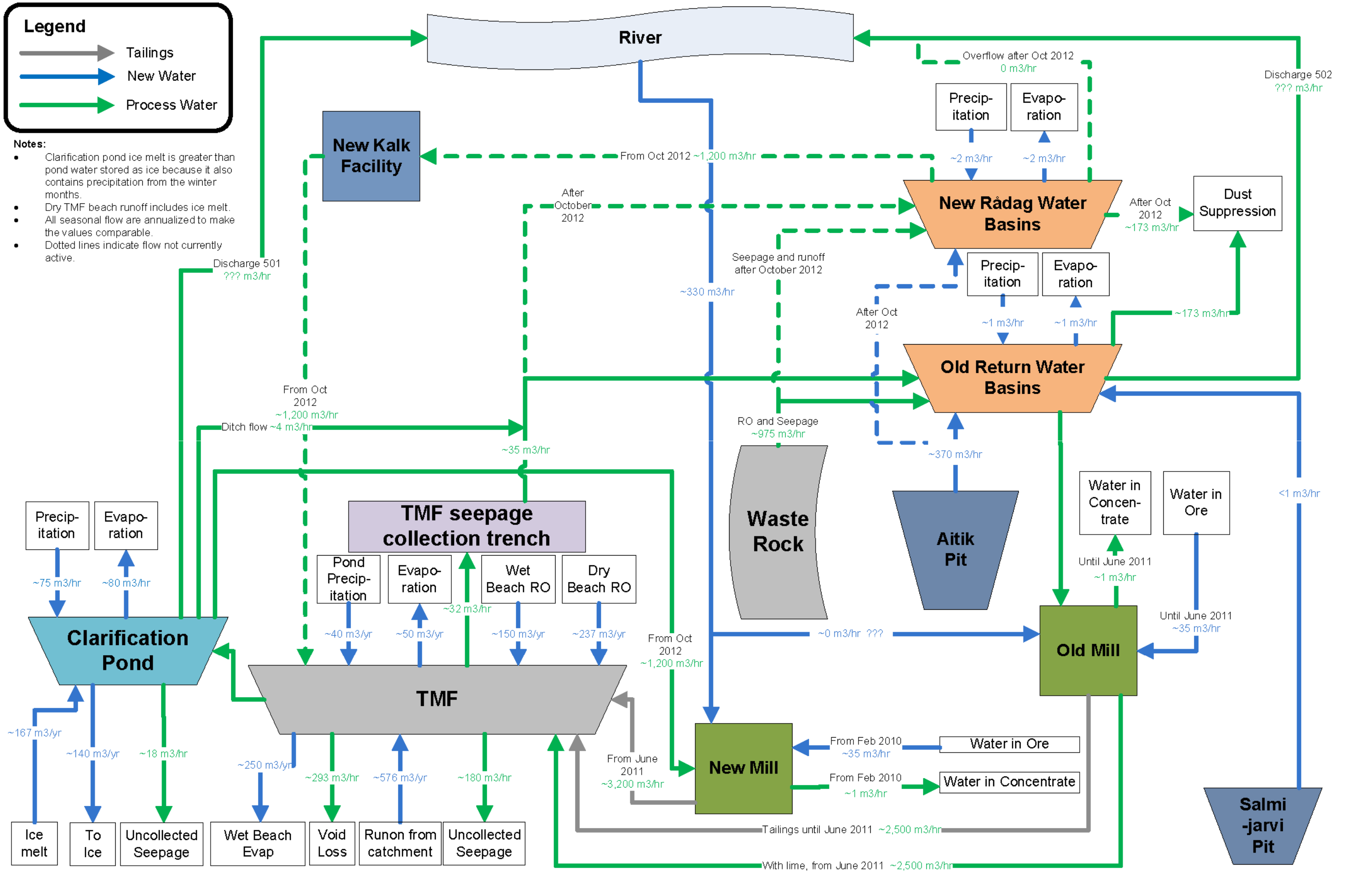
# Aitik: *Model Development*




NEW BOLIDEN

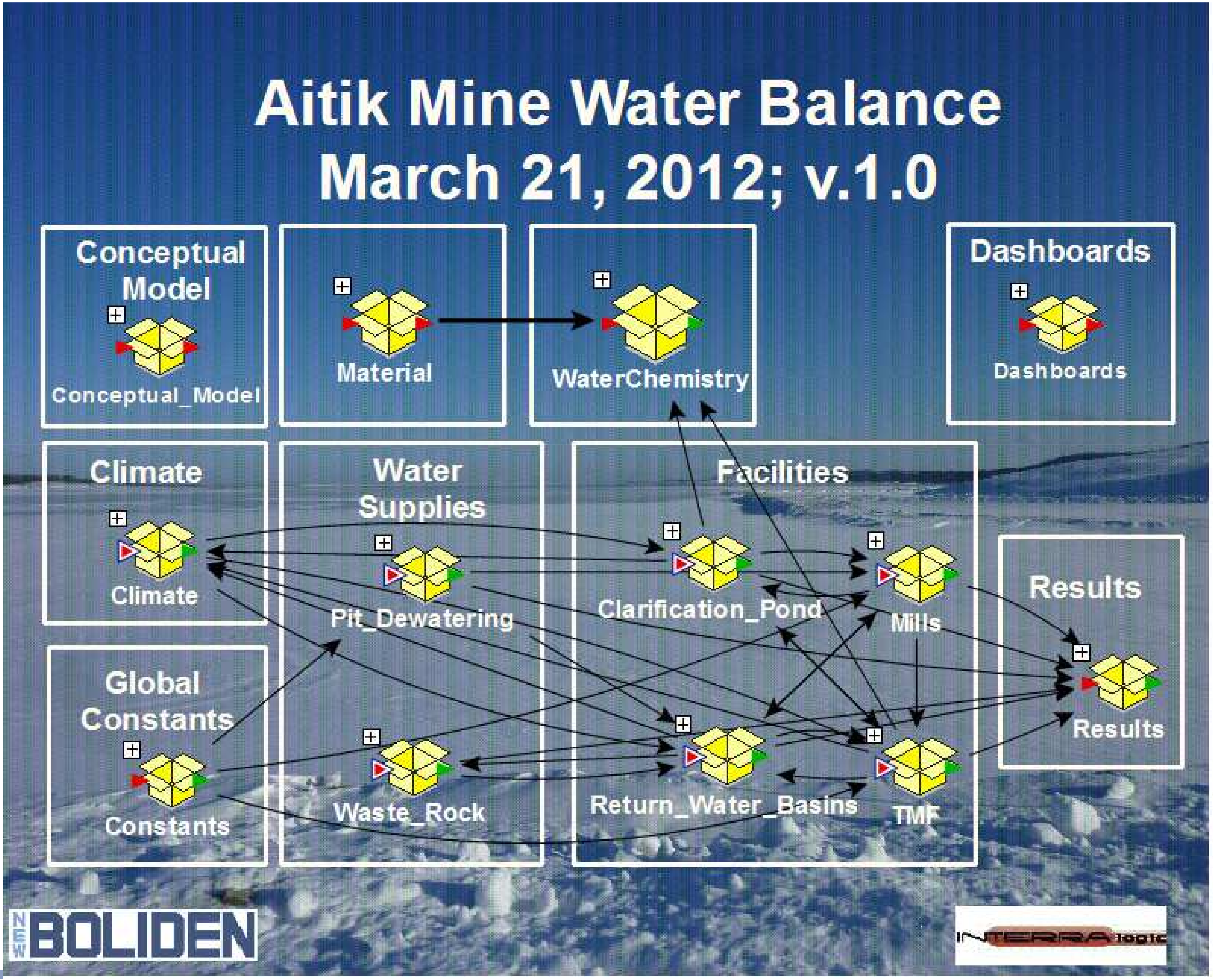
# Aitik Mine Water Balance Conceptual Model

**Wednesday, March 14, 2012**

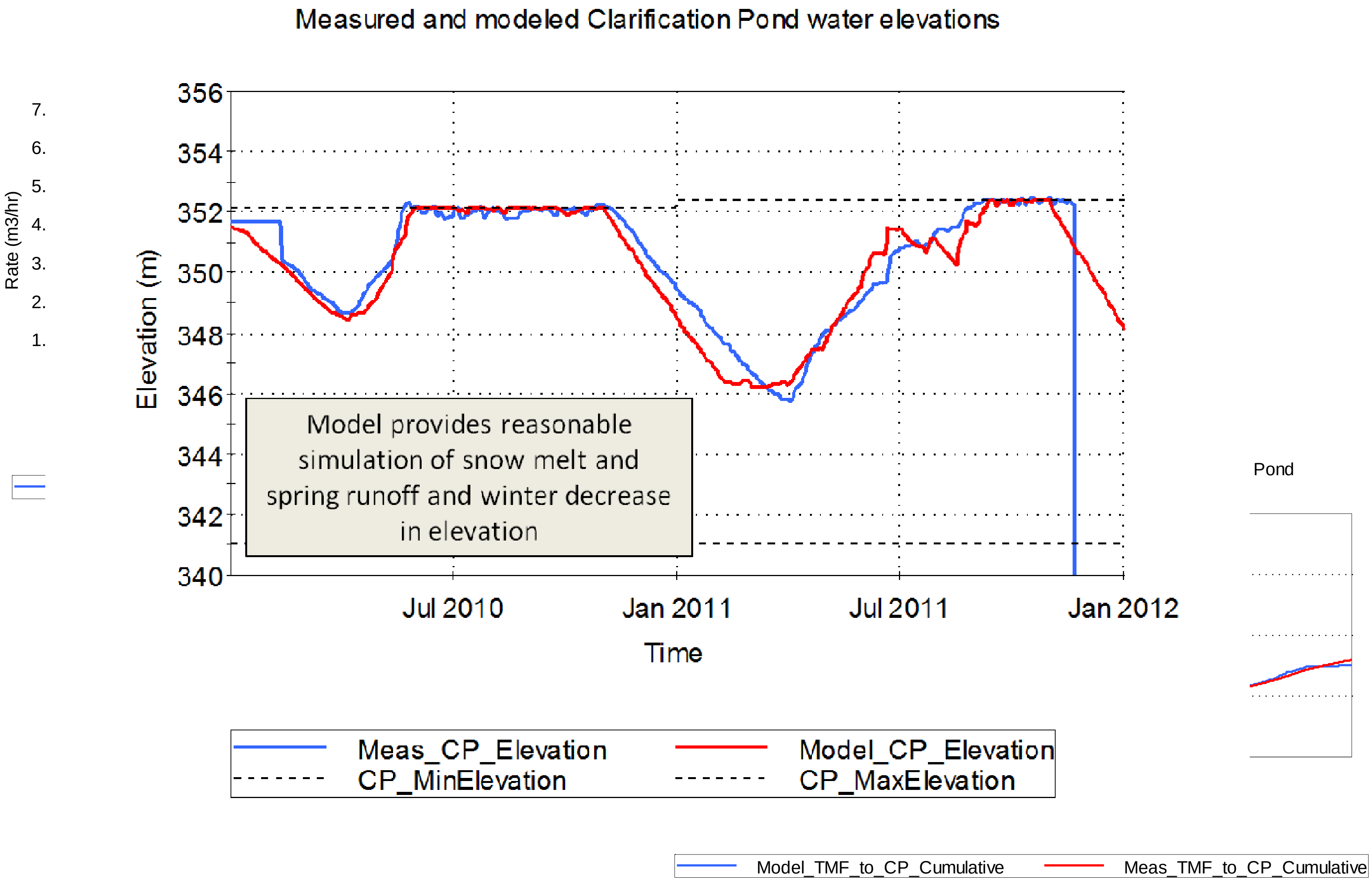



Notes:
- Clarification pond ice melt is greater than pond water stored as ice because it also contains precipitation from the winter months.
- Dry TMF beach runoff includes ice melt.
- All seasonal flow are annualized to make the values comparable.
- Dotted lines indicate flow not currently active.

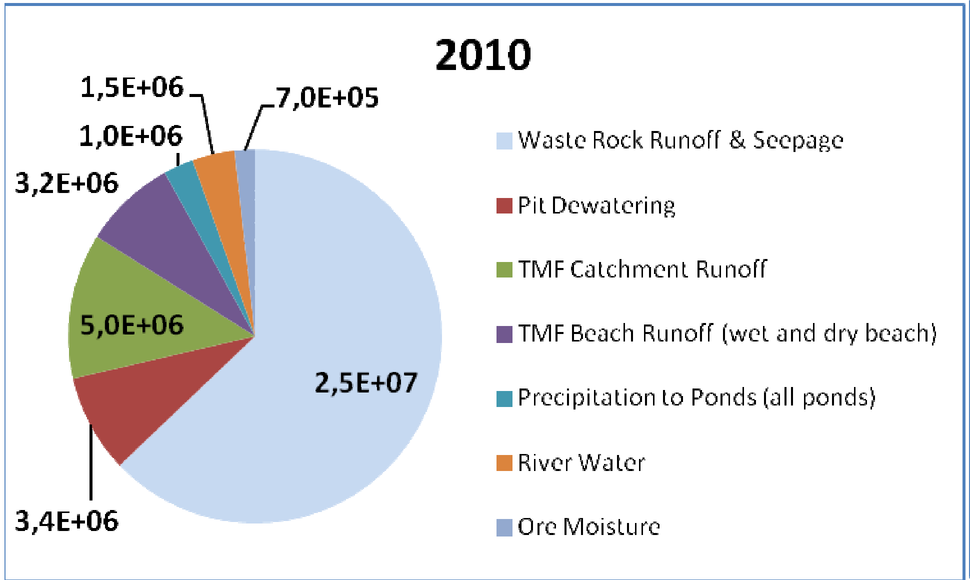
# Aitik: *Goldsim model*

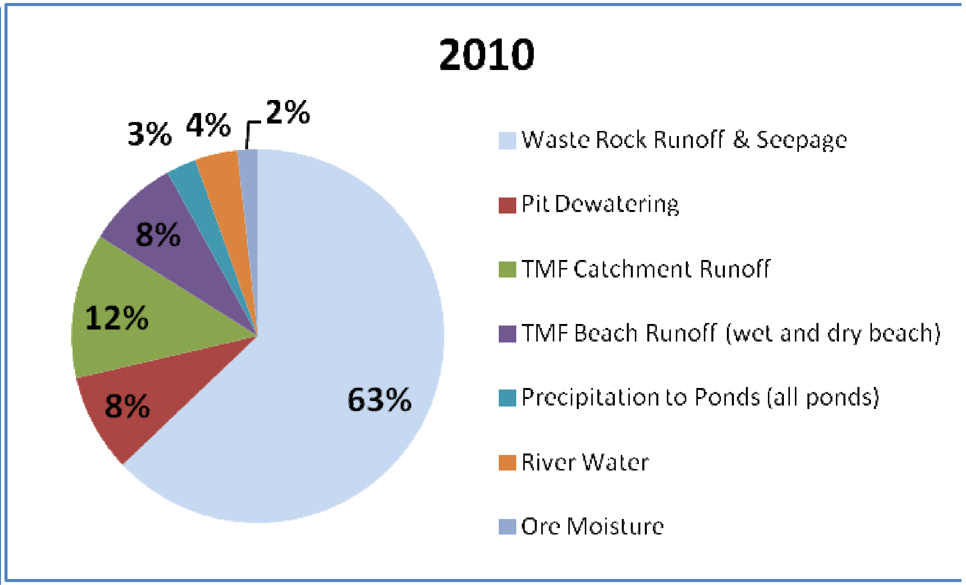


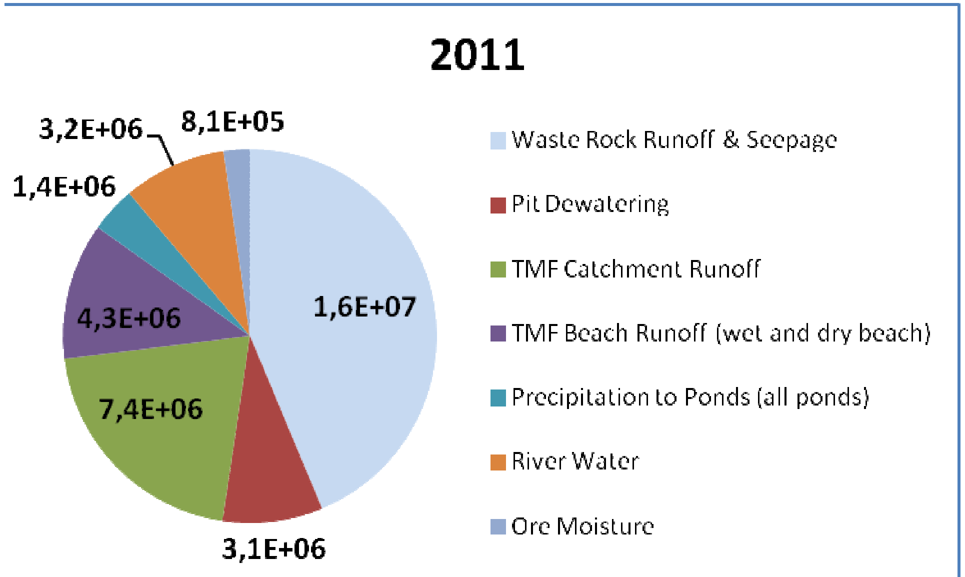
# Aitik: *Model Calibration*

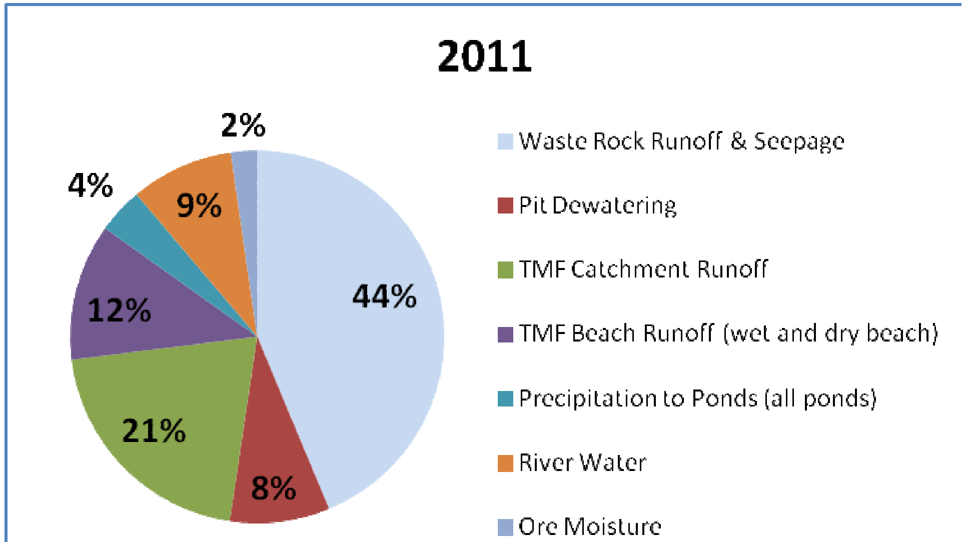


# Aitik, water use: *Sources*



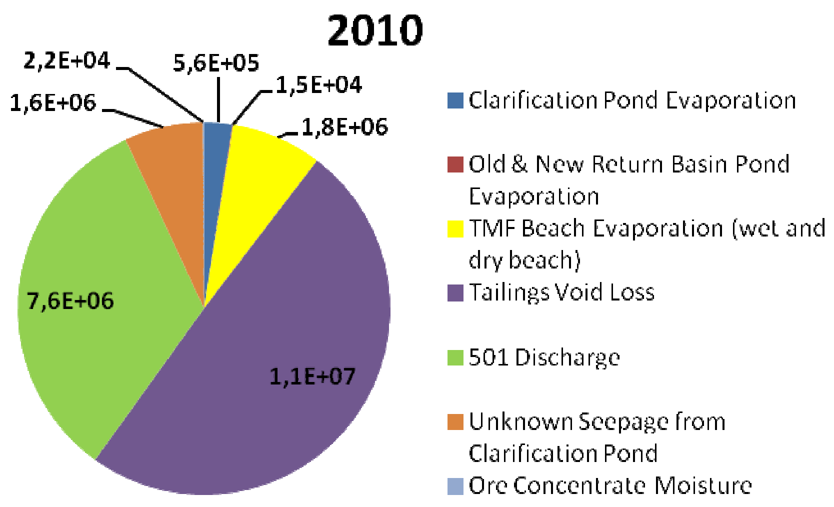



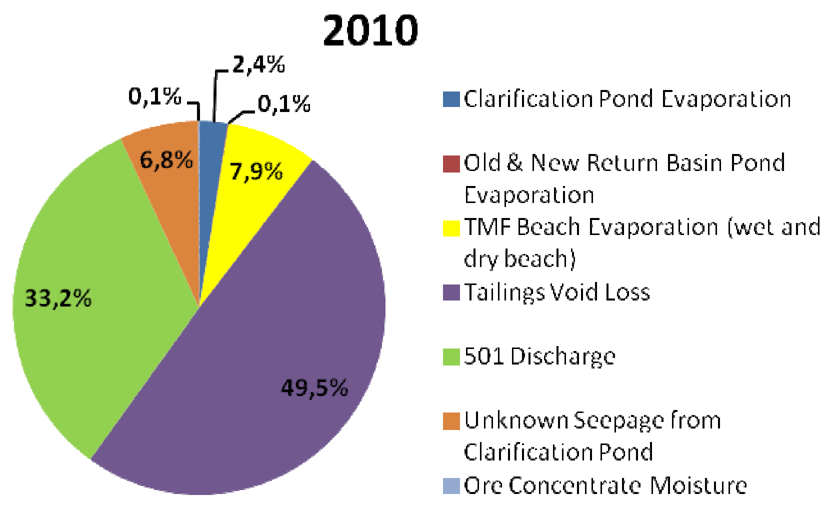



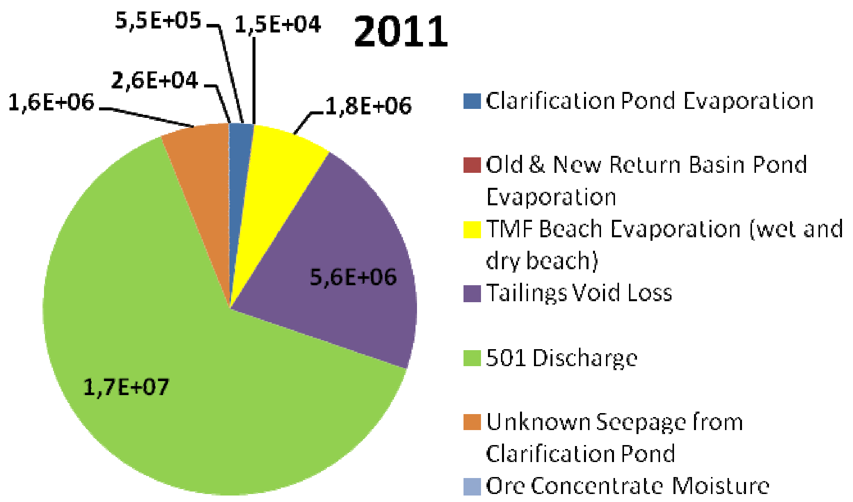



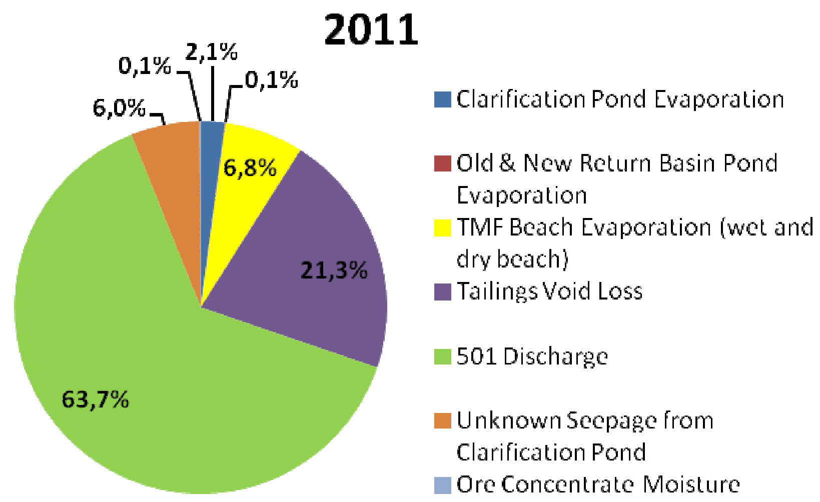

NEW BOLIDEN

# Aitik water use: *Outflows*

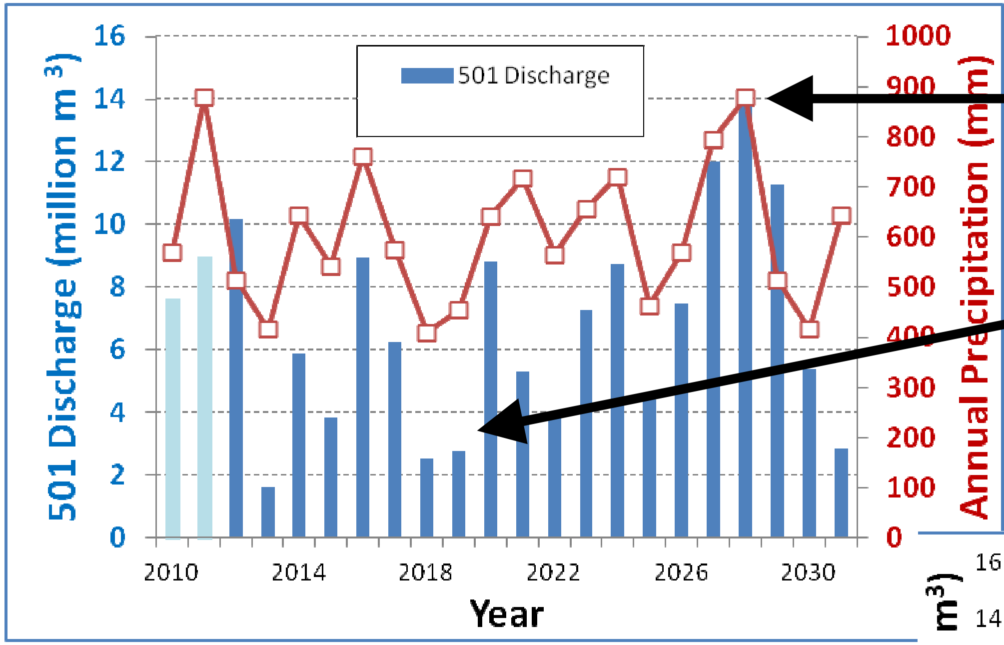


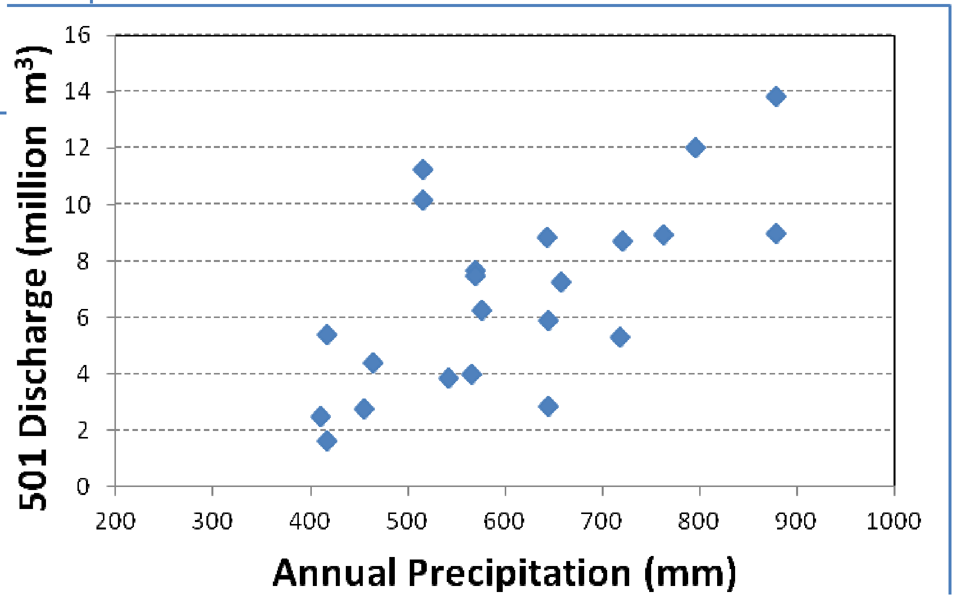
# Aitik: *Discharge rates/Climate*




Consecutive wet years result in greatest potential for discharge

Consecutive dry years result in lowest potential for discharge

- Wet year is 2011 at 878 mm
- Dry Year is 2002 at 410.2 mm
- Average Year is 2001 at 575.2 mm




Relationship between predicted 501 discharge and annual precipitation is not strictly linear due to effects of preceding year

NEW BOLIDEN

# Aitik 45: *Evaluating production/tailings expansion*

- Production increase from 36 to 45 Mton/yr, increase in size of tailings magasine and clarification pond.

- 2 Alternatives considered for HS and LS tailings deposition, additional water storage capacity:
  - Alternative 1: HS-South, Storage South
  - Alternative 2: HS-South, Storage North

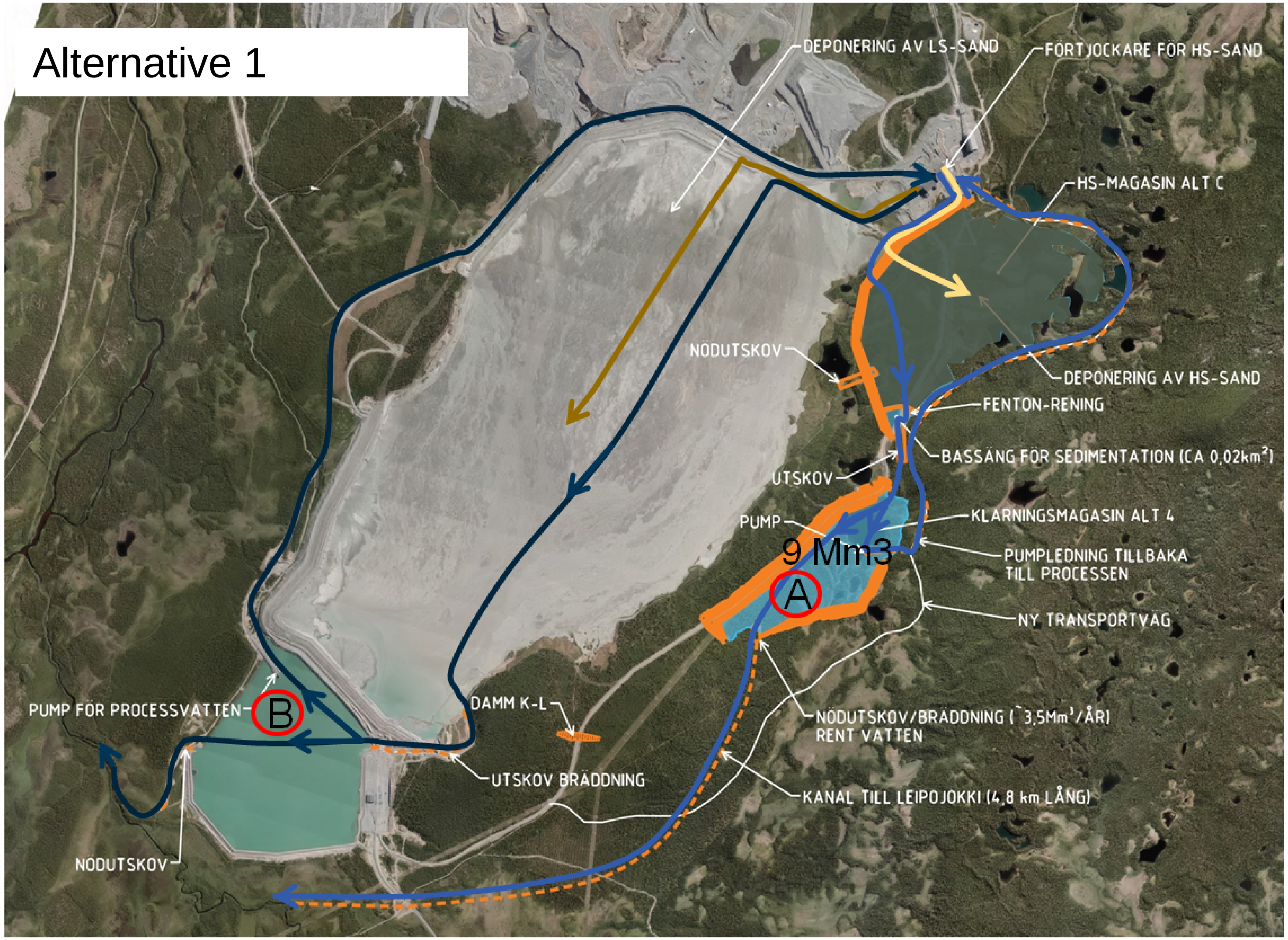
- Alternatives run with multiple wet years, multiple dry years and average year climate scenarios

- Both Alternative 1 and 2 have the full built capacity by 2015, and are essentially null runoff areas (only runoff from dam walls)

- All water in either the existing clarification pond or new north clarification pond is considered to be ”dirty” water.

- All excess water from the HS magasin passes through treatment prior to re-entering the system or being discharged.

# Aitik: *Evaluating production/tailings expansion*




**Flow LS:**
LS-sand:
Water:

**Flow HS:**
HS-sand:
Water:

**Vattenhantering:**

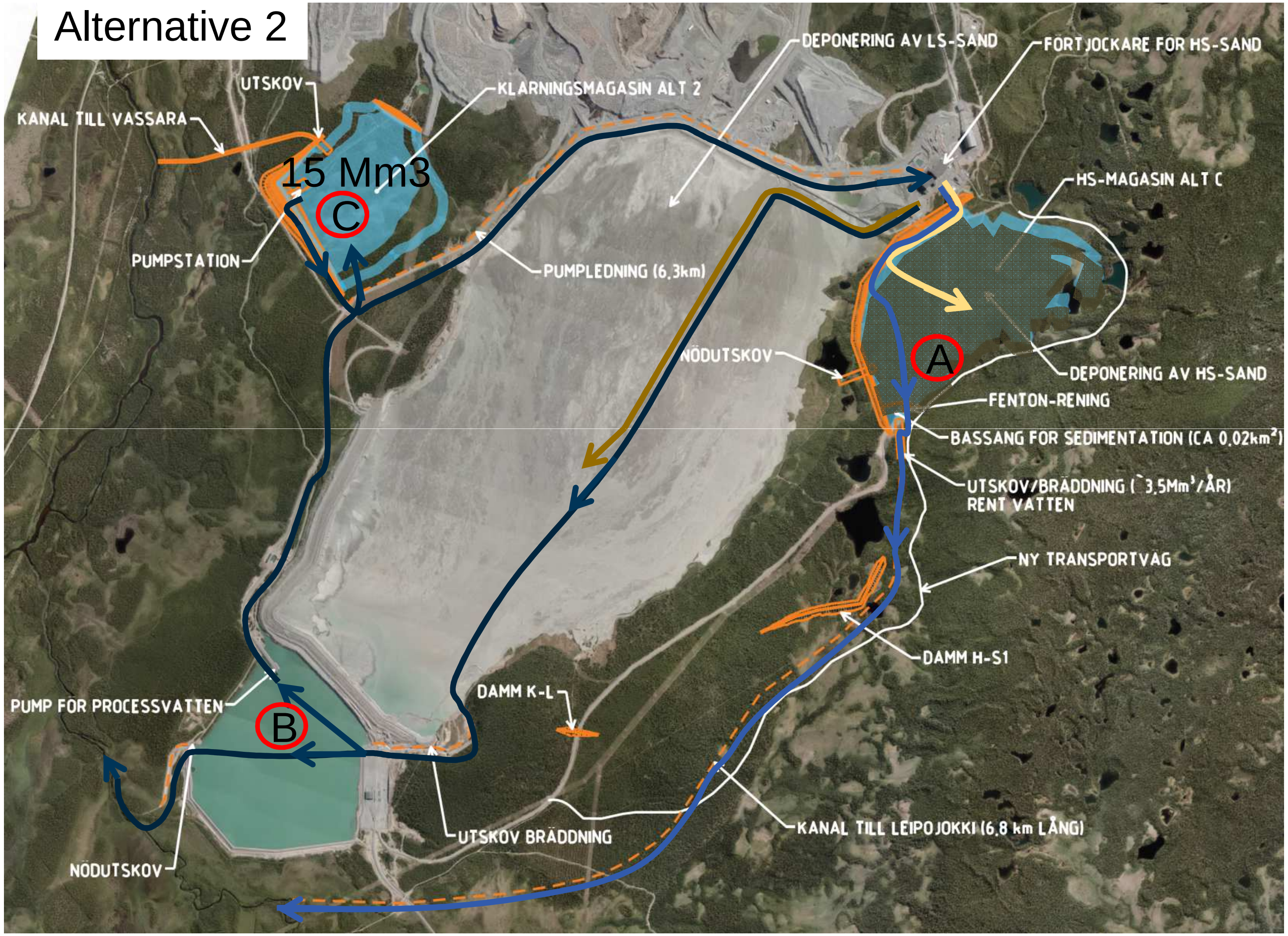
-Excess water released from A

-High flow additional release from B

-Process water from B so it is low in winter (3Mm3), During winter ,process water comes from A

BOLIDEN

# Aitik: *Evaluating production/tailings expansion*




**Flow LS:**

LS-sand:

Water:

**Flow HS:**

HS-sand:

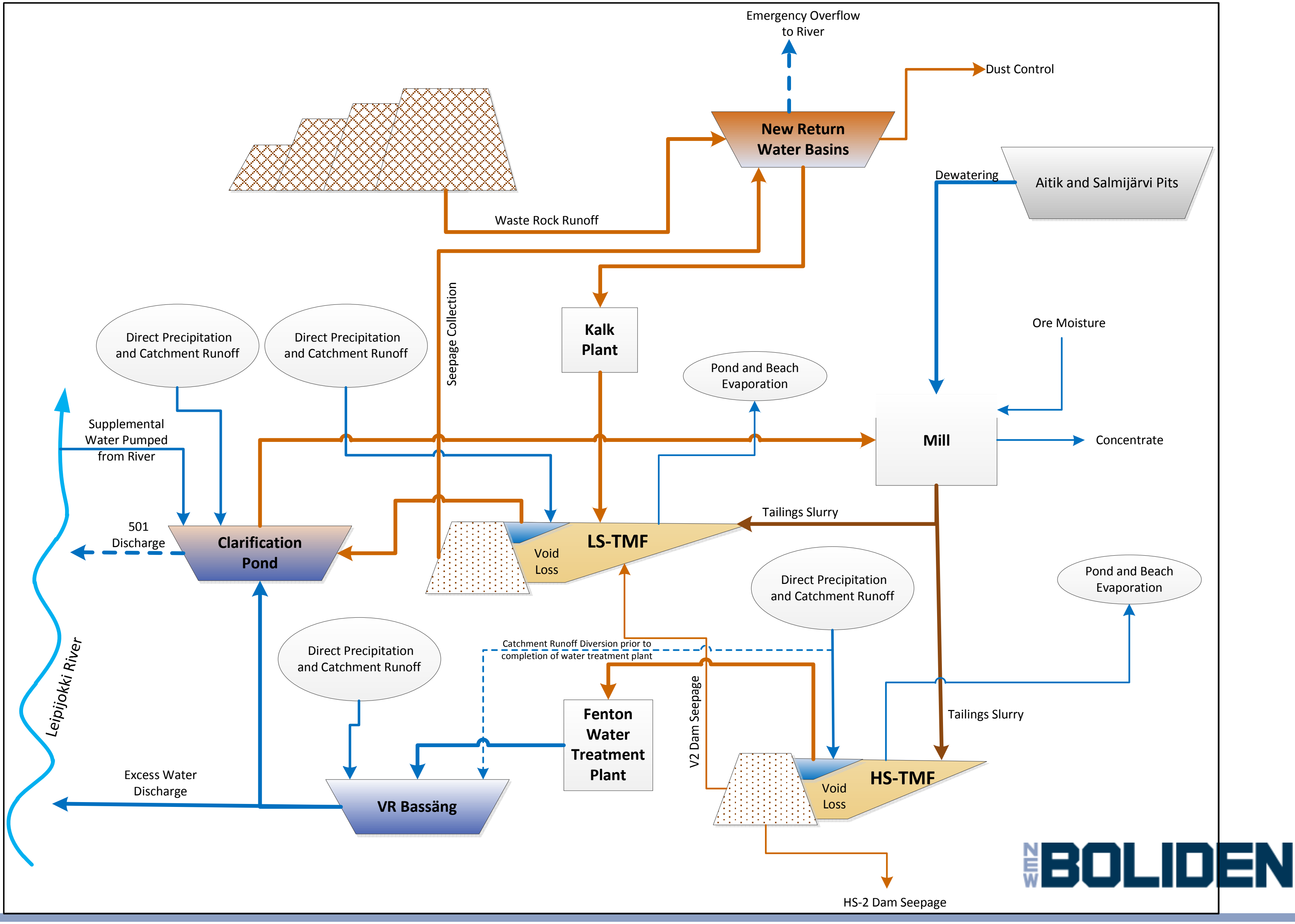
Water:

**Vattenhantering:**

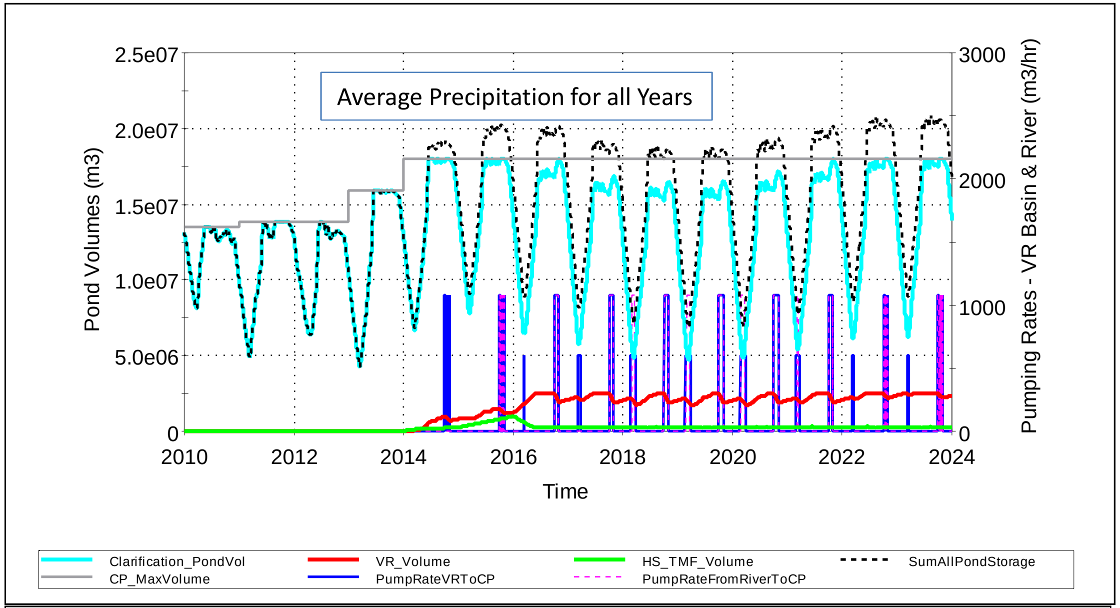
- -Excess water discharge from A
- -Emergency discharge at high flow from either C or B
- -Processvatten tas från B via C

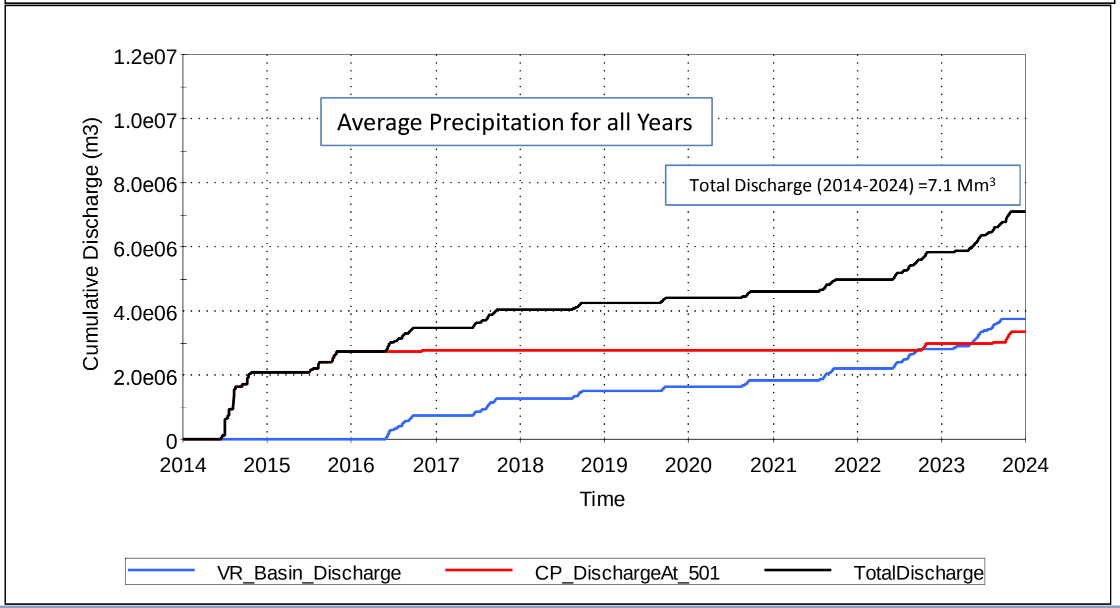
NEW BOLIDEN

# Aitik: *Evaluating production/tailings expansion*



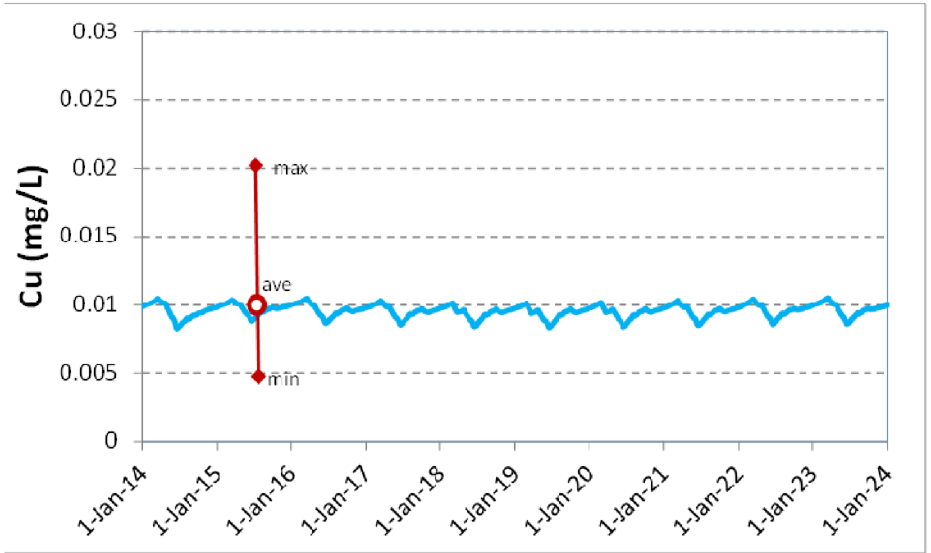
# Aitik: *Evaluating production/tailings expansion -results*

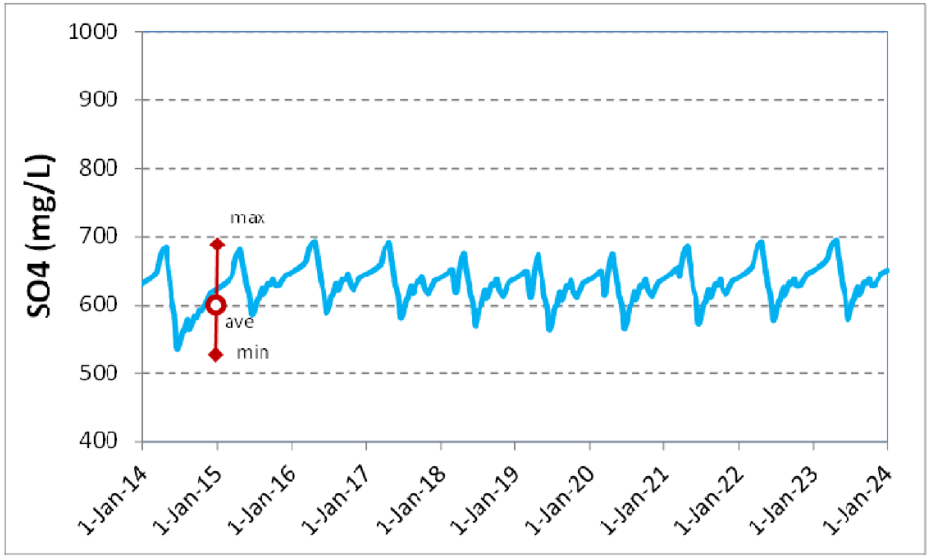


# Aitik: *Evaluating production/tailings expansion -results*

| Precipitation Conditions | VR Basin (Potentially Treated) Discharge ($Mm^3$) / % of Total Discharge | Clarification Pond (Untreated) Discharge ($Mm^3$) / % of Total Discharge | Total Discharge ($Mm^3$) |
|---|---|---|---|
| Average for all years | 3.8 / 54% | 3.3 /46% | 7.1 |
| Average for all years; wet years for 2019-2020 | 6.7 / 53% | 6.0 / 47% | 12.7 |
| Average for all years; Dry years for 2019-2020 | 1.9 / 38% | 3.1 / 62% | 5.0 |




NEW BOLIDEN

# How are we using Water/Mass balance models for water management today?

- Layout-planning and design
  - Sizing of canals, basins, ponds, pumping capacity

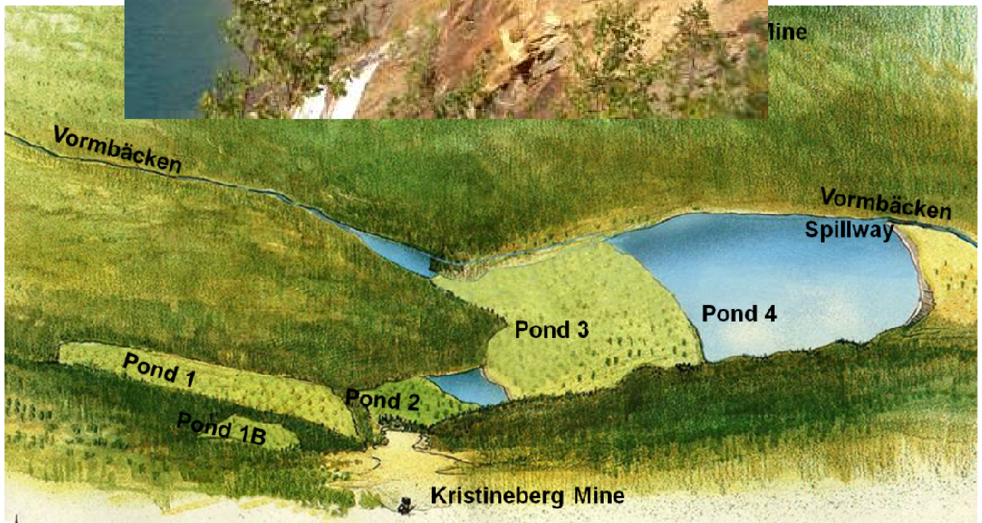
- Estimation of environmental impacts
  - rechage rates/comsumption rates/discharge rates- how much, quality and when
  - Placement of water treatment systems (for best effect)

- Water management
  - Water requirements
  - Optimization of water usage
  - Effects of blending different source streams, recycling water
  - Optimization of discharge
  - Short term prediction for operational conditions
  - Planning for changes-production increases
  - Long term forecast for operations/closure scenarios
  - Redundancy tests
    - Rep stop, climate events, system disturbances-pump failures, construction, power

NEW BOLIDEN

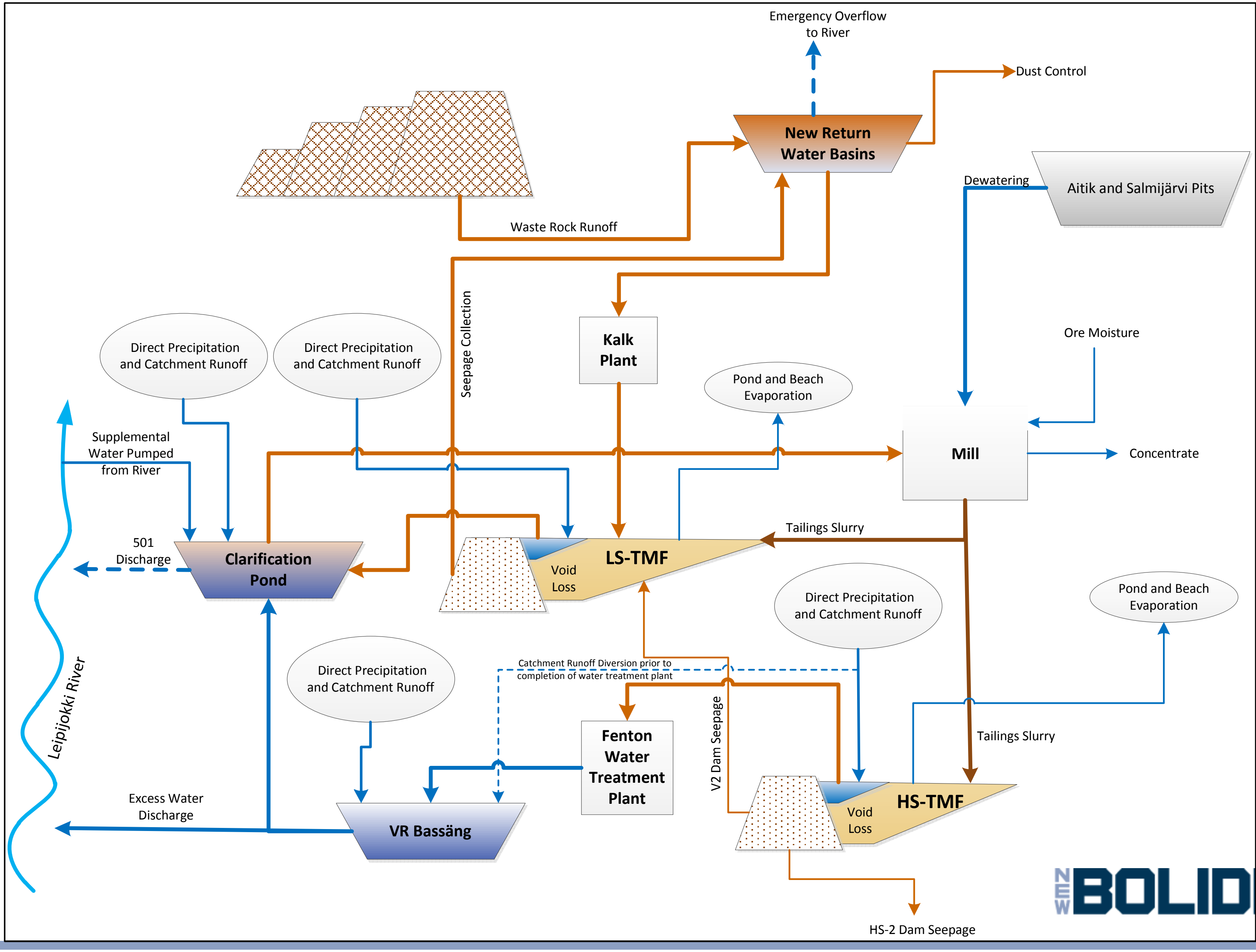
# Closure planning:

- Effects of remediation
  - Changes in flow
  - Changes in chemistry
  - Pit filling and pit lakes
  - Discharge flows
  - Regulators want to know how well it works before you finish it



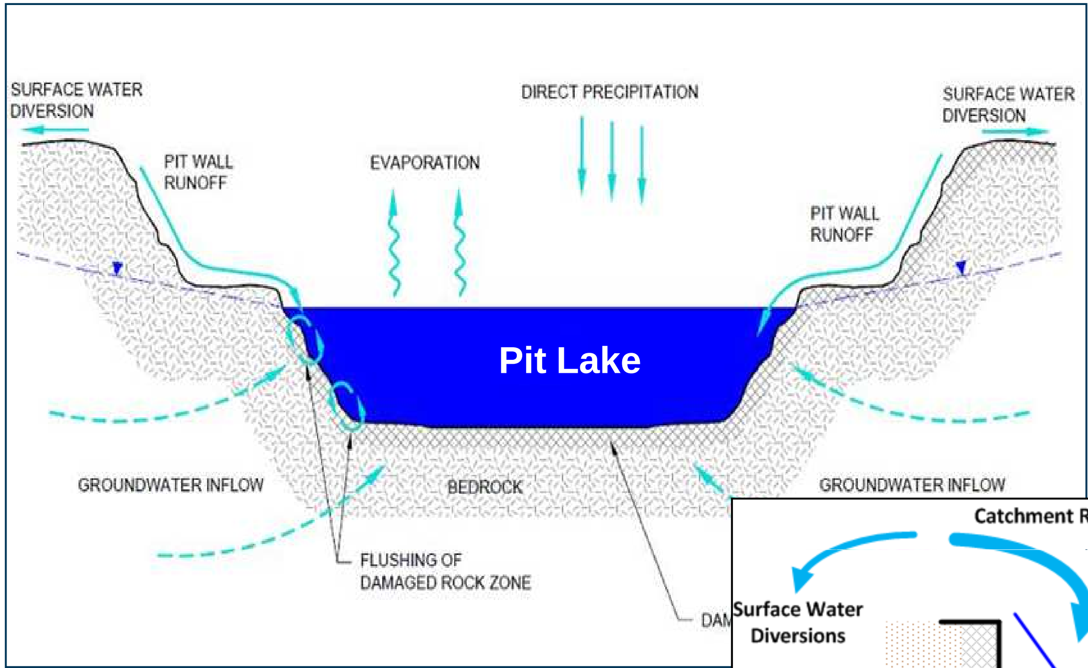

NEW BOLIDEN

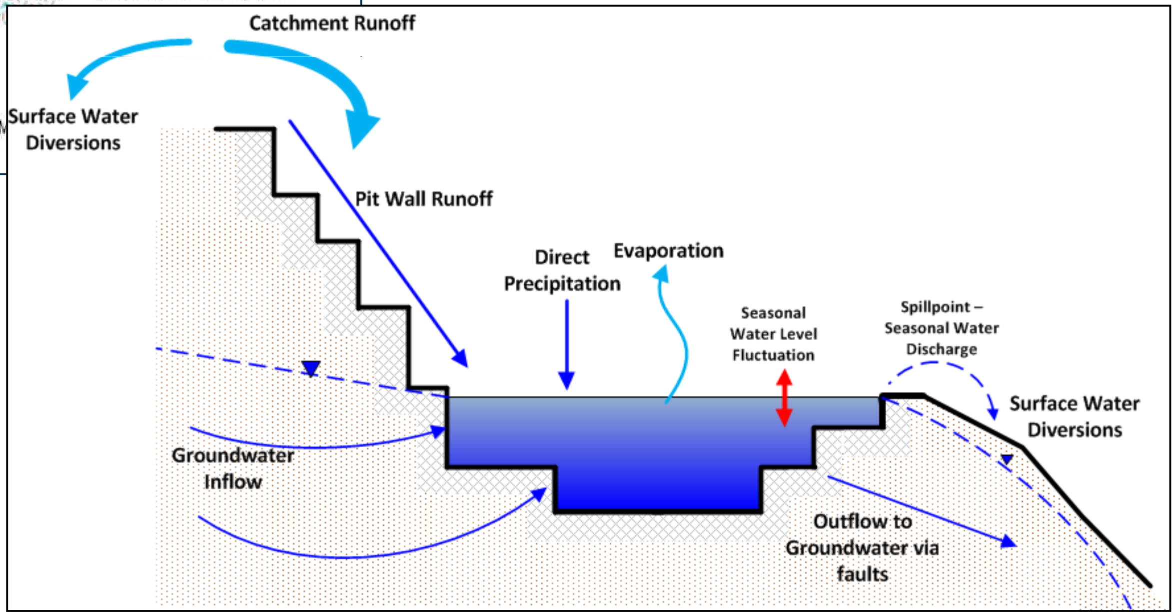
# Closure Planning




NEW BOLIDEN

# Closure planning: Pit Lakes




NEW BOLIDEN

# Closure planning:

**Water Chemistry Prediction**

- **Excel or GoldSim**: Simple mixing models with no geochemical processes
- **Excel + PHREEQC**: Excel for mixing calculations and PHREEQC for geochemical processes
- **GoldSim + PHREEQC (external calculation):** GoldSim for mixing calculations and PHREEQC for geochemical processes
- **GoldSim + PHREEQC (internal calculation):** GoldSim for mixing calculations and PHREEQC for geochemical processes

**Water Column Structure (Stratification)**

- CE-QUAL-W2
- DYRESM

**Water Chemistry and Stratification**

- PITLAKQ (combines CE-QUAL-W2 and PHREEQC)

# Thank you!