The INAP Pit Lakes Database: A Novel Tool for the Evaluation of Predicted Pit Lake Water Quality

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Abstract
On a global scale, pit lake monitoring programs have generated a wealth of data on the geochemistry of pit lakes over the past three decades. These data could provide valuable insights on the likely water quality of future pit lakes and the design of mine closure plans. As such, there is a great need for an online, searchable database of pit lake observations. The International Network for Acid Prevention (INAP) has funded the development of the INAP Pit Lakes Database (http://pitlakesdatabase.org) which compares the surface water chemistry (pH, electrical conductivity, major cations and anions, and trace metals) of existing pit lakes based on location, ore body type, host rock, and commodity. For a user-specified parameter, the database generates pH-versus-concentration plots for all pit lakes color-coded by ore deposit type, plus time-versus-concentration plots for individual lakes. For a given ore body type, the database calculates the minimum, maximum, and median concentrations of each parameter, which can be used to estimate the likely range of future lake water quality in pit lakes developing in similar ore bodies. The database will also calculate the variance between these observed data ranges and predicted values entered by the user. Currently the INAP Pit Lakes Database contains 76 pit lakes with 379 water samples.

Key Words: acid, mine, drainage, prediction, pit lakes

1. Introduction
1.1 Pit Lakes
Pit lakes are formed as a by-product of open pit mining of near surface ore bodies. As the ore body is mined, the water table is lowered in order to prevent the mine from flooding during its operation. After the ore body has been mined economically, the water pumps are shutoff and the water table begins to rebound. The pit lake forms as the water table returns to steady state.

Pit Lakes have the potential of storing mine impacted water. Mine impacted water can be divided into three categories: Acid Mine Drainage (AMD), Neutral Mine Drainage (NMD), and Basic Mine Drainage (BMD). Table 1 summarizes the differences between these different types of drainage (International Network for Acid Prevention 2011).

Table 1. Characteristics of Acidic Mine Drainage, Neutral Mine Drainage, and Basic Mine Drainage (International Network for Acid Prevention 2011)

Acid Mine Drainage	Neutral Mine Drainage	Basic Mine Drainage
- Low pH (<6) - Moderate to elevated metal concentrations - Elevated sulfate concentrations	- Neutral to Alkaline pH (6-8) - Low to moderate metal concentrations - Low to moderate sulfate concentrations	- High pH (>8) - Low metal concentrations - Moderate sulfate, magnesium, calcium and possibly iron concentrations

Since open pit mining of an ore body increases the amount of surface area that has contact with water, both from the increased rock wall surface area and the fracturing of ore body due to blasting,pit lakes have an increased potential to generate mine impacted water quality. Mine impacted water can form from water reactions with the mine walls, waste rock, or microbial reactions.Acid Mine Drainage can form as a result of oxidation of primary Fe-sulfides, sulfate formation, and iron hydroxideprecipitation (Blodau 2006). As a result,there are several pit lakes which have formed poor water quality. Examples include: (1) the Berkley Pit Lake in Butte, Montana (Gammons*et al.* 2003) which is located in a porphyry copper ore deposit and has an average pH of 2.6 and high metal concentrations; (2) the CortaAtalaya Pit Lake in Rio Tinto, Spain which is located in a massive sulfide ore deposit and has a pH of 1.2 and 3,670 g/L Fe, 6,700mg/L Zn, 1,300 mg/L Cu, 159 mg/L As (España*et al.* 2008); (3) the Cortez Pit Lake in Nevada, USA which is located in a massive sulfide ore deposit and has a pH of 7.8 and high sulfide concentrations of approximately 86.5 mg/L (Price *et al.* 1995);and (4) the Gunnar Pit Lake in Saskatchewan, Canada which is hosted in a uranium ore deposit has a pH of 7.8 and highsulfide concentrations of 81.25 mg/L (Tones 1982).

Predicting the water quality of future pit lakes is important in order to determine the environmental impacts that the pit lake will have in the area. Future pit lake water quality predictions are receiving close scrutiny from regulatory agencies due to the potential impacts that pit lake water can have on local surface and groundwater reservoirs (Davis and Eary 1999). For this reason, regulators generally require numerical predictions of the water quality of future pit lakes as a part of the mine permit process. Depending on filling rates and climate conditions, it can take these pit lakes 50 to 300 years to reach steady state (Eary and Schafer 2009). Predicting the water quality of future pit lakes involves complicated and costly numerical models. These numerical models must take into account climate, pit area, pit depth, pit volume, rock geochemistry, water geochemistry, and limnology of the pit lake. Most prediction programs cannot take into account all of these factors. Programs such as MINTEQA2 (Allison *et al.* 1991), PHREEQC (Parkhurst and Appelo 1999), and EQ3/6 (Wolery and Daveler 1992) are currently used in the geochemistry prediction process for future pit lake water quality. Davis and Eary (1997) give a summary of a 250 year prediction of the Pipeline Pit located in a carlin-type gold deposit in the Cortez Pipeline Gold Deposit, Battle Mountain, Nevada (Davis and Eary 1997).Tempel*et al*.(2000)created a 8.5 year prediction of the North Pit Lake in Getchell Mine, Nevada hosted in a carlin-type gold deposit. Castendyk and Webster-Brown (2007) discusseda 55 year prediction for the Martha Pit located in New Zealand in a andesite hosted epithermal gold deposit.

Currently, there is a major gap in the ability to validate pit lake predictions. This gap could be filled by two types of studies. The first type of study is to develop a collection of pit lake water quality data over time to see how the pit lake water chemistry changes over time. This type of study is impractical before mining since the pit lake won't exist for 50 to 300 years after the end of the mining process. The second type of study is to develop a database of existing pit lake water quality and mine site data which could be used in a searchable database to compare predicted pit lake water data to existing pit lake water data (Schafer and Eary 2009). The results of pit lake predictions can be compared to existing pit lakes in similar geological settings to check the accuracy and the validity of the numerical model. The INAP Pit Lakes Database provides a tool that will allow the validation of predicted pit lake data using existing pit lakes in similar ore deposits.The database is located at http://pitlakesdatabase.org.

1.2 Objectives

This paper will provide an overview of the different capabilities of the INAP Pit Lakes Database.First, the design of the database, the type of data contained in the database, and the different search options will be reviewed. Nextthe results of the different searches produced from the database will be discussed, followed by a discussion on how the data can be interpreted from the database, current problems, and the future work.

2. Methods

2.1 Database Design

The database was designed using three different programming languages for the front-end of the database:Microsoft's Active Server Pages (ASP), Visual Basic Script (VBS), and JavaScript. The front-end of the database handles the user interface and all of the data. Microsoft Access is being used for the back-end of the database. The back-end of the database is what stores all of the data.The database is being hosted off of a Dell server running Windows Server 2008 R2 withMicrosoft's Internet Information Services (IIS) 7.5 as the web core. The web core is the program that allows the website to be accessed by the Internet.The database is designed to be compatible with any server running Windows Server. The programming languages ASP, VBS, JavaScript, and Microsoft Access were used due to their compatibilities with different web cores (e.g. Apache, IIS). The database was designed to be compatible with most Windows webservers.

2.2 Data Contained in the INAP Pit Lakes Database

The database is designed to store the physical properties of a mine site and the geochemical values of the water samples for each pit lake. Table 2 shows the types of data that are stored in the database for each pit lake. All of the geochemical units that are stored in the database are in mg/L. Although many of the samples contained in the database are at depth, only surface water samples are used in the searches.Currently, all of data contained in the database were obtained from published literature.

Table 2. List of the type of data stored in the INAP Pit Lakes Database. All geochemical values are stored as mg/L unless otherwise noted in parenthesis. Section A shows data related to the physical properties of the mine site. Section B shows all of the data related to the geochemistry of the water samples taken for each lake.

A. Site Data (Single Entry Per Lake)	
Group:	**Currently Supported Data:**
Lake Information	Lake Name
Geology	Ore Body Type, Commodity, Host Rock
Geography	Country, State/Region
Other Information	Other relevant information on the lake or mine site
References	Sources of the site data
B. Water Quality Data (Multiple Entries Per Lake)	
Group:	**Currently Supported Data:**
Sample Information	Date Taken, Sample Depth (m), Temperature (°C)
pH and Trace metals	pH, Ag, Al, As, Bi, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Se, Te, Tl, U, V, Zn
Major Cations and Anions	Ca, Cl, CO_3, HCO_3, K, Mg, Na, SO_4
Other Elements	B, Ba, Be, Br, Cs, F, Ga, Li, Sc, SiO_2, Sn, Sr, Ti
Nutrients	NH_3, NH_4, NO_2, NO_3, PO_4
Physiochemical Parameters	Electrical Conductivity (µS/cm), TDS, DO, ORP (mV), pe, Eh
Other Information	Other relevant information on the water sample
References	Sources of the water sample data

The different ore deposits that are contained in the database along with the number of lakes and water samples for each ore deposit are shown in Table 3. Currently there are 19 ore deposits, 76 pit lakes, and 379 water samples contained in the database

Table 3. Summary of ore deposits currently contained in the database. The number of lakes, number of total water samples, and number of surface water samples are shown for each ore deposit.

Ore Deposit:	Number of Lakes:	Number of Total Water Samples:	Number of Surface Water Samples:
Bakala Iron	4	5	4
Carlin-Type Gold	9	99	74
Copper	2	2	1
Gold	1	1	1
Lead	1	1	0
Lignite	1	1	1
Massive Sulfide	19	59	34
Porphyry Copper	3	96	22
Porphyry Copper-Molybdenum	4	42	17
Porphyry Hosted Gold	3	3	3
Quartz-Adularaia	4	23	23
Quartz-Alunite	1	1	1
Quartzite	2	2	2
Quartzitic Sandstone	2	2	2
Sediment-Hosted Epithermal	1	7	7
Silica Sand	1	1	0
Taconite	10	89	78
Uranium	3	13	6
Zinc	1	1	0

2.3 Search Options

There are five different search options designed into the database which include: Search by Site Data, Time Series Charts, Search by Geochemical and Physiochemical Data, Predictive Search, and pH Charts. The search options allow the user to compare existing pit lake data, or to compare predicted pit lake data to existing pit lake data.

The database performs several calculations during a search, which only use surface water samples. The database converts pH to molarity in calculations. Lake averages for each parameterare calculated and shownon a summary page.For each parameter, the minimum, maximum, mean, median, and standard deviation values are calculated for an ore body using all of the lakes that are associated with the individual ore deposit.

2.3.1 Search by Site Data (Ore Body Type)

Search by Site Data allows the user to search and compare existing pit lakes to other existing pit lakes based on the physical properties of a mine site. Table 2A shows the search options for the Search by Site Data.Using this search, the user will be able to compare lakes that exist in the same ore bodies, host rock, commodity type, or geographic location.

After the search is performed, a summary page is generated which shows all of the lakes contained in the different ore deposits. From this page, the user can select a lake and view a detailed report on the individual pit lake. This report includes all of the information that is stored on the pit lake, along with all of the water samples in the database for that pit lake.

2.3.2 Time Series Charts
In the detailed results page of a pit lake, the user can generate Time Series charts of a parameter plotted against time (Figure 2) for all of the data of an existing pit lake. These charts allow the user to visualize geochemical trends within an existing pit lake. Time Series charts also give the user the ability to see any anomalies in the data (ie, sudden spike in pH) so that the user can investigate the cause of these anomalies.

2.3.3 Search by Geochemical and Physiochemical Data
Search by Geochemical and Physiochemical Data allows the user to search and compare existing pit lake data based off of the geochemical and physiochemical properties of the water samples independent of ore body type.This search gives the user the ability to compare all of the pit lakes that would fall under a given pH range or given range of concentrations. For example, the user can search for lakes that contain AMD (pH <6), NMD (pH between 6 and 8), and BMD (pH > 8), or As concentrations between 0.01 and 0.1 mg/L. Table 2B shows the search options for the Search by Geochemical and Physiochemical Data.

2.3.4 Predictive Search
Predictive Search allows the user to compare the results of a predictive pit lake model to existing pit lake data in the same or similar ore bodies. The database will also compare the predicted model to other ore bodies if one of the existing pit lakes found exists in multiple ore bodies. The user would use this search in order to validate predicted pit lake water chemistry. This search shows the user how close their prediction is with other existing pit lakes in the same ore body.

2.3.5 pH Charts
The pH Charts option allows the user to generate pH charts of all existing pit lake data in the database.The pH is plotted on the x-axis and the concentration of the selected element, compound, or physiochemical parameter is plotted on the y-axis. This search gives the user the ability to compare all of the data in the database in order to look for trends. In this search, the user can view every ore deposit on one graph, or they can select an individual ore deposit and view all of the water samples for that ore deposit.

3. Results
The results of the searches are presented in different ways. First, a summary page is shown after user preforms a search. Pit lakes on this page are divided into the different ore deposits, and averages for surface water chemistry are shown for each individual lake in the ore deposit. On the summary page (Figure1) the user can also view a detailed report on an individual pit lake by clicking on the pit lake name. In the detailed report the user can view all the physical properties of the mine site, the statistical data for the pit lake water quality (minimum, maximum, mean, median, standard deviation, and a number of water samples for each element), each individual water sample that is stored in the database for that pit lake, and the reference showing the origin of the data.

3.1 Results of Search by Site Data
Figure 1 shows a screenshot of the summary page for the Search by Site Datagenerated by a search for carlin-type gold deposits. A total of 9 pit lakes were found that exist in a carlin-type gold deposit. According to the data currently contained in the database, the carlin-type gold deposit has a range of pH from 3.08 to 9.36 with a mean of 4.26, a standard deviation of 3.76, and 71 surface water samples. As concentration ranges from 0.007 to 25.8 mg/L with a mean of 1.28 mg/L, standard deviation of 3.64, and 73 surface water samples. SO_4^{2-} concentrations ranges from 21.4 to 4860 mg/L with a mean of 709.5 mg/L, standard deviation of 1,169.95, and 65 surface water samples.

9 Pit Lakes Found.

Carlin-Type Gold Ore Deposits

	pH	Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Sb	Se	SO4	Zn	HCO3	NO3	TDS
Adelaide Crown	7.8	-	1.000e-2	5.000e-2	1.000e-1	5.000e-3	-	-	2.700e-2	5.000e-1	-	-	6.500e+1	-	2.150e+2	5.000e-1	4.500e+2
Betze-Post	8.48	-	3.235e+0	-	-	2.238e-3	-	-	5.275e-3	-	1.099e-2	6.750e-4	6.675e+1	-	-	-	-
Big Springs	7.87	2.063e-1	5.033e-2	5.000e-3	5.640e-2	5.000e-3	2.393e-1	2.000e-4	1.482e-1	5.000e-3	-	1.267e-2	4.305e+2	3.225e-2	1.328e+2	2.050e-1	7.438e+2
Boss Pit	8.25	-	1.003e+0	1.100e-2	4.500e-2	4.410e-2	7.015e-1	1.667e-3	1.627e-1	5.667e-2	9.050e-4	1.057e-1	2.642e+3	4.500e-2	1.294e+2	5.290e+1	1.177e+4
Chimney Creek	8.28	-	2.563e-2	-	-	5.800e-3	-	-	1.078e-3	-	7.200e-4	7.000e-4	2.445e+1	-	-	-	-
Cortez Pit	7.86	-	2.714e-2	6.000e-3	1.033e-2	6.000e-3	1.143e-1	6.467e-4	2.300e-2	5.286e-3	-	5.833e-3	1.042e+2	6.571e-3	2.892e+2	1.117e+0	4.823e+2
Getchell Mine	5.66	-	1.327e-1	5.000e-3	2.000e-2	2.833e-2	1.020e+0	1.400e-1	2.077e+0	5.000e-2	-	2.333e-3	1.453e+3	2.500e-1	-	-	2.223e+3
North Pit	7.67	-	3.800e-1	-	-	5.000e-3	1.600e-1	-	1.300e-1	5.000e-3	-	3.000e-3	1.570e+3	2.000e-2	-	-	2.420e+3
Summer Camp Pit	3.93	2.800e-1	1.715e+0	6.000e-3	-	1.908e-1	6.486e+0	-	4.269e-1	2.000e-3	-	-	3.932e+2	4.625e+0	-	-	6.493e+2
Min	3.08	2.000e-1	7.000e-3	2.000e-3	1.000e-2	1.200e-3	4.000e-2	2.000e-4	2.000e-5	1.000e-3	1.300e-4	2.000e-4	2.140e+1	2.000e-3	9.800e+1	6.000e-2	2.450e+2
Max	9.36	3.500e-1	2.580e+1	5.000e-2	1.970e-1	1.060e+0	4.930e+1	2.000e-1	4.300e+0	5.000e-1	5.310e-2	4.200e-1	4.860e+3	2.680e+1	3.380e+2	1.950e+2	1.566e+4
Median	8.01	2.125e-1	8.600e-2	6.000e-3	2.000e-2	2.000e-2	3.700e-1	1.000e-3	4.200e-2	6.000e-3	1.010e-3	5.000e-3	3.580e+2	5.000e-2	1.550e+2	1.000e+0	7.140e+2
Mean	4.26	2.308e-1	1.286e+0	9.045e-3	3.686e-2	9.192e-2	3.653e+0	2.288e-2	2.732e-1	4.400e-2	5.902e-3	2.245e-2	7.095e+2	2.849e+0	1.955e+2	1.914e+1	2.015e+3
Std. Dev.	3.76	0.05	3.64	0.01	0.04	0.2	10.04	0.06	0.81	0.1	0.01	0.07	1169.95	5.86	79.15	45.3	3588.91
n	71	6	73	22	21	65	47	19	50	24	16	34	65	54	16	17	53

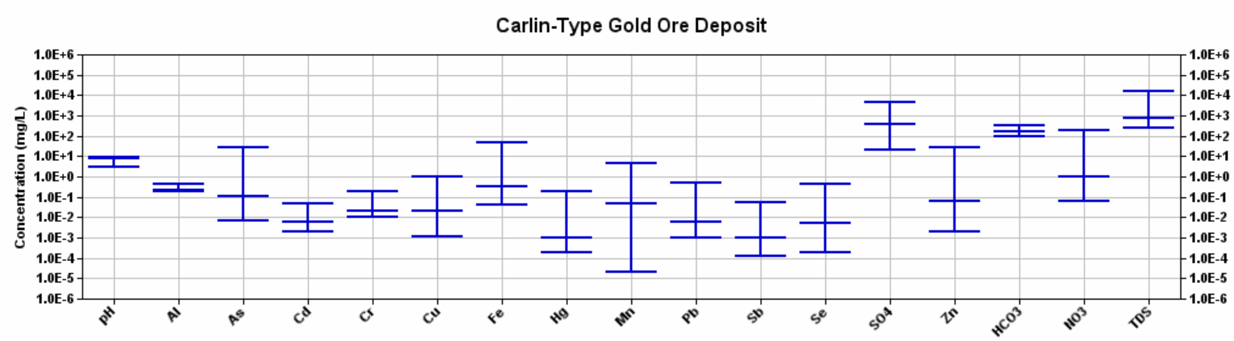

Figure 1. Screenshot of the summary page of a "Search by Site Data". The results were generated by a search for carlin-type gold deposits. A list of the pit lakes (in blue text) with the average surface water quality for selected parameters are listed for each ore deposit found. The minimum, maximum, median, mean, and standard deviation of the overall surface water quality for the entire ore deposit is listed at the end of each table. A whisker chart is then shown for the ore deposit with concentration on the y-axis and the element, compound, and physiochemical parameter on the x-axis. These whiskers show the minimum concentration (lower blue line), maximum concentration (upper blue line), and median concentration (middle blue line) for the entire ore deposit.

3.2 Results of Time Series Charts

Figure 2 shows a screenshot of a Time Series chart for the Summer Camp Pit Lake in Nevada. This chart was generated by: (1) running a "Search by Site Data" search for carlin-type gold deposits (Figure 1);(2) clicking on the name "Summer Camp Pit" in order to generate a detailed report; and (3) clicking on pH in the "Statistical Data for Summer Camp Pit Lake" section of the detailed report. Figure 2 shows that, pH dropped from approximately 7 to 3 during May of 1991, then returned to a pH of 7 in July of 1991.

The database will also generate time series charts of any parameter for the individual pit lake. These charts show concentration on the y-axis and time on the x-axis, and allow the user to see concentration trends inan existing pit lake. Using Time Series charts, trends and anomalies can be observed and investigated further.

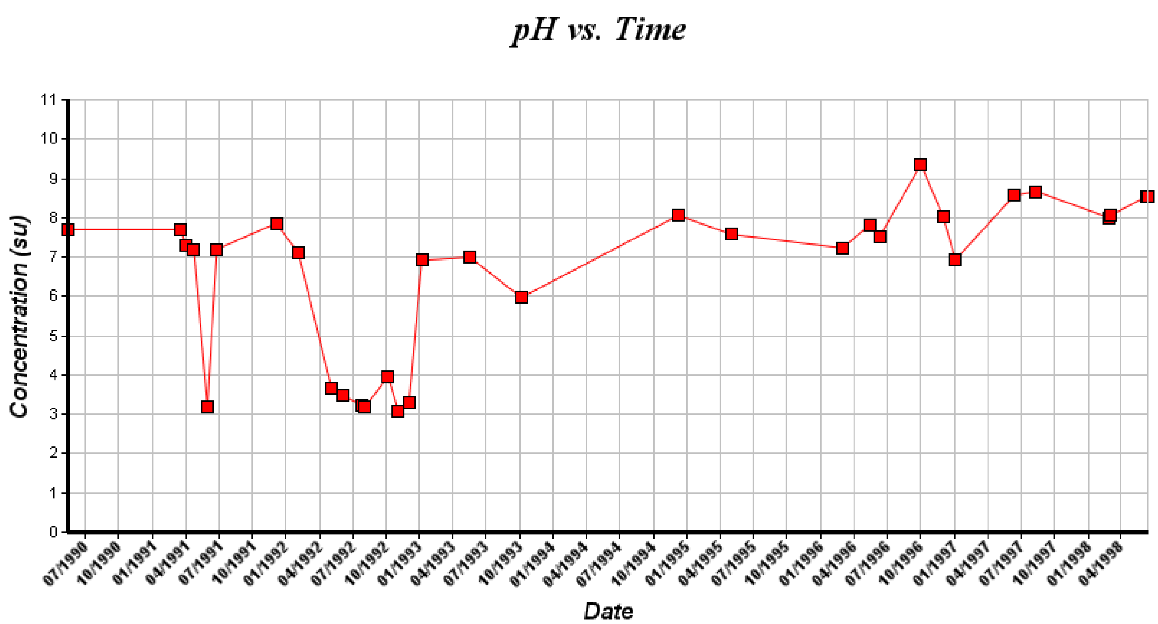

Figure 2. The time series chart of pH vs. time for the surface water of Summer Camp Pit Lake, Nevada. Data was obtained from Bowell(2002) and Filipek*et al*, (2003). Concentration is on the y-axis and time is on the x-axis.

3.3 Results of Search by Geochemical and Physiochemical Data

When the user preforms a "Search by Geochemical and Physiochemical Data", such as a search for low pH pit lakes, the database would generate an output formatted exactly as the output generated in the "Search by Site Data" (Figure 1). However, the results ofthis would be independent of ore deposit type.

3.4 Results of Predictive Search

Figure 3 shows a screenshot of the summary page for a Predictive Search. This search was generated by comparing a 50 year prediction of the Pipeline Pit (Davis and Eary1999), shown in Table 4, to other existing pit lakes in the database. The Pipeline Pit is hosted in a carlin-type gold deposit in Battle Mountain, Nevada. The database compared the predicted pit lake to the 9 existing pit lakes which are in the database. According to the database, the values for pH, As, Cd, Cu, Hg, Pb, Se, SO_4, Zn, Cl, K, Mg, Na, Ba, F, and Total Dissolved Soilds were within the ranges of existing pit lakes hosted in carlin-type gold deposits. However, the values for Ag, Cr, Fe, and Ca were less than the ranges of existing pit lakes hosted in carlin-type gold deposits.

Table 4.50 year prediction of Pipeline Pit in Battle Mountain, Nevada. All values in mg/L Pipeline Pit hosted in a carlin-type gold deposit (Davis and Eary 1999).

Pipeline Pit (50 year) Prediction										
Element:	**pH**	**As**	**Ba**	**Cd**	**Ca**	**Cl**	**Cr**	**Cu**	**F**	**Fe**	**Pb**
Concentration:	8.81	0.03	0.09	0.004	2.7	40	0.007	0.006	1.9	0.0009	0.001
Element:	**Mg**	**Hg**	**Mn**	**K**	**Se**	**Ag**	**Na**	**TDS**	**SO_4**	**Zn**	
Concentration:	16	0.001	0.03	14	0.008	0.3	110	671	113	0.12	

9 Pit Lakes Found.

Carlin-Type Gold Ore Deposits

	pH	Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Se	SO4	Zn	Ca	Cl	K	Mg	Na	Ba	F	TDS
Predicted	8.81	3.000e-1	3.000e-2	4.000e-3	7.000e-3	6.000e-3	9.000e-3	1.000e-3	3.000e-2	1.000e-3	8.000e-3	1.130e+2	1.200e-1	2.700e+0	4.000e+1	1.400e+1	1.600e+1	1.100e+2	9.000e-2	1.900e+0	6.710e+2
Min	3.08	5.000e-3	7.000e-3	2.000e-3	1.000e-2	1.200e-3	4.000e-2	2.000e-4	2.000e-5	1.000e-3	2.000e-4	2.140e+1	2.000e-3	7.900e+0	1.500e+0	1.000e+0	3.410e+0	1.400e+0	7.800e-4	1.520e-1	2.450e+2
Max	9.36	2.300e-1	2.580e+1	5.000e-2	1.970e-1	1.060e+0	4.930e+1	2.000e-1	4.300e+0	5.000e-1	4.200e-1	4.860e+3	2.680e+1	5.300e+2	4.310e+3	2.210e+1	1.300e+2	3.100e+3	2.500e-1	7.820e+0	1.566e+4
Median	8	1.000e-2	1.100e-1	6.000e-3	2.000e-2	2.000e-2	3.100e-1	1.000e-3	4.500e-2	6.000e-3	5.000e-3	3.600e+2	6.300e-2	8.980e+1	2.610e+1	1.130e+1	2.180e+1	8.255e+1	4.500e-2	2.940e+0	7.380e+2
Mean	4.26	3.025e-2	1.232e+0	9.045e-3	3.686e-2	9.192e-2	3.419e+0	2.288e-2	3.101e-1	4.400e-2	2.245e-2	7.379e+2	2.864e+0	1.437e+2	4.959e+2	1.124e+1	3.457e+1	4.425e+2	8.121e-2	3.335e+0	2.051e+3
% Dev.	34.81	81.681	95.246	38.676	68.078	87.746	99.475	91.624	82.356	95.556	47.45	73.441	91.957	96.312	85.071	10.952	36.723	60.18	5.135	27.409	50.695
n	71	16	73	22	21	65	47	19	50	24	34	65	54	51	38	36	42	38	34	35	53

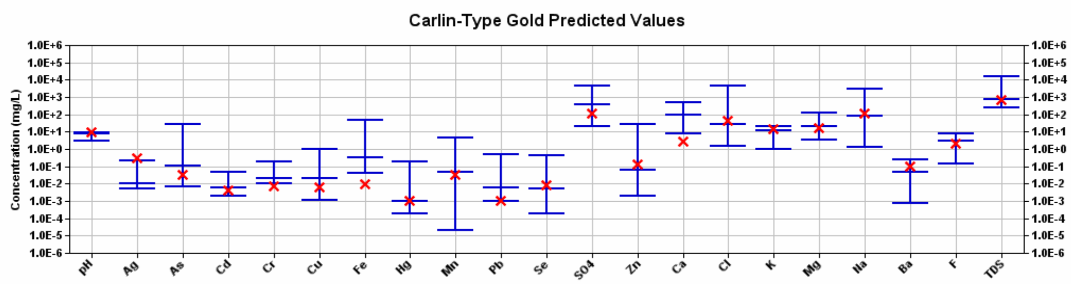

Figure 3. Screenshot of the summary page for a Predictive Search generated by comparing predicted data for a future pit lake (Table 4) to carlin-type gold deposits.A table is generated showing the predicteddata that the user entered, followed by the minimum, maximum, median, mean, percent deviation, and number of surface water samples used for the ore deposit. A whisker chart is then shown for the ore deposit with concentration on the y-axis and the element, compound, and physiochemical parameter on the x-axis. These whiskers show the minimum concentration (lower blue line), maximum concentration (upper blue line), and median concentration (middle blue line) for the entire ore deposit. A red x on the whisker charts represents the predicted data.

3.3 pH Charts

The user can also generate pH vs. concentration plots of all the existing pit lake data in the database (Figure 4). In these charts, the concentration of the selected element, compound, or physiochemical parameter is on the y-axis and pH is on the x-axis. If no ore deposit is selected in the search input, then all of the pit lakes in the database are shown.Figure 4 shows the pH chart for copper. In this chart a general exponential trend can be seen in the overall data: as pH increases the copper concentration decreases. This can also be seen within individual ore deposits. An example of this can be seen in the data for carlin-type gold deposits shown in the green dots in Figure 4.

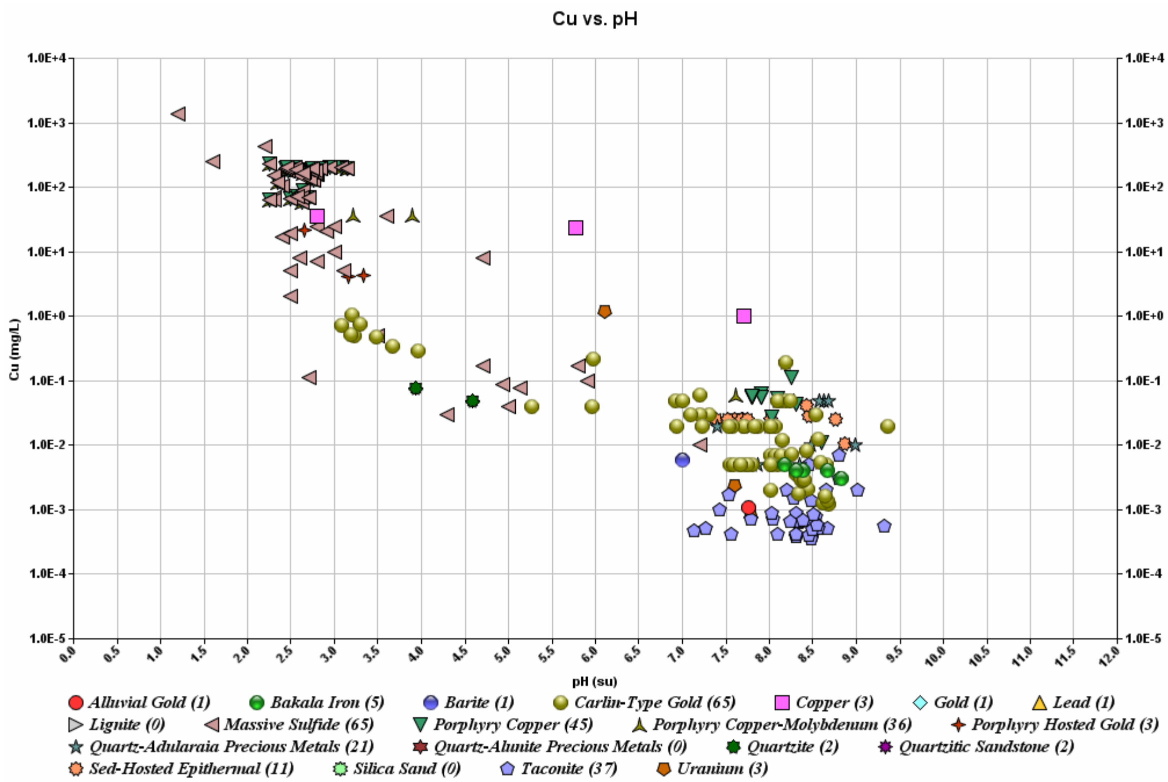

Figure 4.pH chart for Cu vs. pH for the entire database. The legend shows each ore deposit with the number of water samples in parentheses.

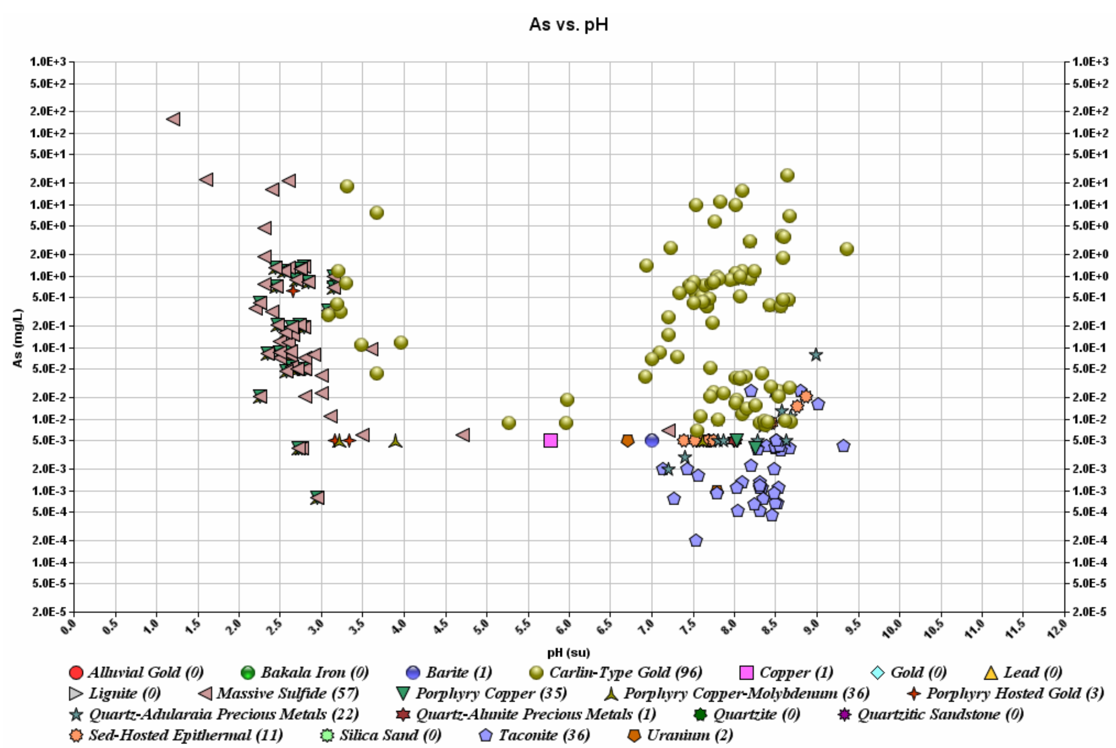

Figure 5.pH chart for As vs. pH.The legend shows each ore deposit with the number of water samples in parentheses.

Figure 5 shows the pH chart for arsenic. In this chart, a general bimodal trend can be seen in the overall data. Arsenic concentrations decrease between pH values 1 to 4, and increasing between pH values 6 to 9.5.

4. Discussion

4.1 Uses of the Database

Currently the database can be used to compare existing pit lakes based on ore body type, host rock, commodity, and geochemical ranges. This allows researchers to see the current state of existing global pit lakes and to see global trends in relation to ore deposit.Through the database it can be seen that no two pit lakes are exactly the same. This is shown in the high standard deviations shown in Figures 1 and3. A lot of the data for individual ore bodies span several orders of magnitude. This is due to the fact that no two ore deposits are the same. Site specific variations such as pit lake size, water depth, rainfall rates, evaporation rates, differences in host rocks, wall rock mineralogy, and weatheringcan result in differing water quality in pit lakes in the same deposit types.

The database can also be used to validate numerical prediction of a future pit lake. Figure 3 shows a search comparing predicted data from the Pipeline Pit Lake (Davis and Eary 1999)and indicates that the values for Ag, Ca, Cr, and Fe plot outside the min-max range of the 100 samples and 9 lakes.This allows the modeller to go back and investigate why those values are outside the ranges of current pit lakes and adjust the predicted model if needed. Not every pit lake in existence is contained in the INAP Pit Lakes Database. Since each pit lake is unique, it is a possibility that a predicted pit could have geochemical values outside the ranges of existing pit lakes. For example, in the predictive model for Pipeline Pit Lake, the predicted value for Cr is 0.003 mg/L lower than the minimum concentration value in the database. Likewise the predicted value for Fe is 0.031 mg/L lowerthan the minimum concentration value in the database. This value is an order of magnitude lower than the lowest current value. Even though it could be possible that this is a valid concentration, the modeller would still need to go back and resolve this difference.

Using the INAP Pit Lakes Database we can see trends in existing pit lake data. Two different types of trends are shown in the pH charts: an exponential trend (Figure 4) and a bimodal trend (Figure 5). Table 5 shows the parameters in relation to the type of trend they show with pH. In the exponential trend, the overall results for all the pit lakes in the database show that as pH increases the concentration decreases regardless of ore deposit type. This includes divalent cations,some anions, and SO_4^{2-}. Individual ore bodies, for example carlin-type gold, also show this type of relationship. One possible explanation for this trend is relating this to the adsorption of cations on hydrous ferric oxide. In the case of the Cu^{2+}cation, percent adsorbed increases from 0% to 100% over a pH from 4 to 6.5 respectively (Drever 1997). Dissolved concentrations of Cu, and othercations, would follow the opposite trend of the adsorption curve. In this case, in water with low pH there would be high concentrations of Cu and the concentration of Cu would decrease as the pH increases.This, however, does not explain SO_4^{2-}.

The bimodal trendshows clustering of parameter values at both low pH ($2<pH<4$) and high pH ($7<pH<9$) (Figure 5).Relating thisbimodal trend to the adsorption of cations and anions on hydrous ferric oxide (HFO) can provide some insight as to the cause of this trend. In the case of arsenic, the adsorption of arsenate on HFO shows a strong pH dependence, with decreased adsorption observed at both low and high pH.Drever (1997), for example, showed a decrease inAsO_3^{3-}adsorptionfrom 80% to 40%over a pH drop of7.5 to 4.0, and a further decreasein adsorption to 40%at pH 10.5.Data for dissolved concentrations of As and other anions in the Pit Lake Database are generally consistent with these adsorption principles, although ascarcity of data over the pH range 4 to 7 precludes definitive conclusions. Arsenic, for example, shows peak values at both low pH and high pH, consistent with the pH-dependence adsorption of arsenate.Chromium also shows bimodal behaviour, with higher concentrations observed at both low and high pH (data not shown). While for the Cr^{3+}cation percent adsorbed increases from 0% to 100% over a pH from 3 to 5.5, adsorption of the Cr^{6+} anion (CrO_4^{2-}) decreases from 100% to 0% over a pH from 6 to 8 (Drever 1997). Given the likely predominance of Cr^{6+}in the aerobic surface waters of the pit lakes, the bimodal concentration distribution can likely be explained by pH-dependent sorption characteristics of anion species.

Table 5. The relationships between trends and parameters.

Relationships Between Trends and Elements	
Trend:	**Parameters:**
Exponential	Al, Cd, Co, Cu, Fe, Mn, Ni, Pb, Se, SO_4, Zn,F
Bimodal	Ag, As, Cr, Mo, Sb, Se, Tl, V, Ca, Cl, HCO3, K, Mg, Na, B, Ba, Be, Br, Li, Sn, Sr, Ti, U, NO_3, PO_4, Conductivity, TDS, DO, Eh

4.2 Current Problems and Sources of Error

The INAP Pit Lakes Database only uses published literature sources which often contain incomplete datasets. Even if multiple published literature sources are used for the same pit lake, a complete temporal dataset cannot be obtained. This causes concentration vs. time gaps in the database which need to be filled. There is also a lack of complete geochemical parameters of pit lake water quality in published literature sources. This causes concentration gaps in the database which also need to be filled. One way to fill these gaps would be to obtain more complete datasets from mining companies and regulatory agencies. Another potential source of error is that only surface water is being used in the calculations of the INAP Pit Lakes Database. While the database does store water samples taken at depth, it will not use them in any of the calculations. The database does allow the user to download the surface and depth data for individual pit lakes.

5. Conclusion

The INAP Pit Lakes Database can be used for two purposes: (1) testing a predictive model against existing pit lake water quality data, and (2) obtaining an overall better understanding of geochemical trends in existing global pit lake water quality. The INAP Pit Lakes Database shows bimodal and exponential trends in existing pit lake water quality data, which can be explained by adsorption of cations and anions on hydrous ferric oxide.

There is still more work that needs to be done on the database. More data needs to be entered into the database. The more pit lakes that are contained in the database, the better a tool it will become. Data gaps in the current datasets also need to be filled. This database is a “living document” that will be filled over time.

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Acronyms

ASP	Active Server Pages
BMD	Basic Mine Drainage
IIS	Internet Information Services
INAP	International Network for Acid Prevention
NMD	Neutral Mine Drainage
VBS	Visual Basic Script