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FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

Date: **November 24, 2015**

To: **Interested Parties**

From: **Lisa Fay, MDNR Project Manager**
Douglas Bruner, USACE Project Manager
Michael Jiménez, USFS Project Manager

Re: **NorthMet Mining Project and Land Exchange**
Final Environmental Impact Statement
Notice of Errata Sheet – Reference-Related Corrections to the Final EIS

The Minnesota Department of Natural Resources (MDNR), the U.S. Army Corps of Engineers (USACE), and the U.S. Forest Service (USFS) have jointly prepared the Final Environmental Impact Statement (FEIS) for the NorthMet Mining Project and Land Exchange. The FEIS describes the anticipated environmental and socioeconomic impacts of the proposed PolyMet Mining, Inc. (PolyMet) NorthMet Mining Project and Land Exchange, located near the cities of Hoyt Lakes and Babbitt in northeastern Minnesota. The FEIS also responds to substantive comments received during the public comment periods for the Draft EIS and the Supplemental Draft EIS. The FEIS is posted on MDNR's website at: http://www.dnr.state.mn.us/input/environmentalreview/polymet/index.htm l.

Interested Parties are hereby notified of an Errata Sheet detailing reference-related corrections to the Final EIS. The errata is posted on the MDNR's EIS project website as listed above. A copy of the errata may also be obtained upon request by contacting Lisa Fay, MDNR EIS Project Manager, at lisa.fay@state.mn.us.

Public review copies of the FEIS **and errata** are available at the following locations: the MDNR Library, 500 Lafayette Road, St. Paul; the MDNR Regional Office at 1201 East Highway 2, Grand Rapids; the MDNR-Division of Lands and Minerals Regional Office at 1525 Third Avenue East, Hibbing; the Hoyt Lakes Public Library at 206 Kennedy Memorial Drive, Hoyt Lakes; the Babbitt Public Library, 71 South Drive, Babbitt; the Duluth Public Library, 520 West Superior Street, Duluth; and the Minneapolis Public Library, 300 Nicollet Mall, Minneapolis.

The Co-lead Agencies take the opportunity to note the FEIS is available for public review for the period ending **December 14, 2015** at 4:30 PM CT.

Please submit comments by email to NorthMetFEIS.dnr@state.mn.us. All emails should include a name and legal mailing address. Comments may also be submitted by mail to:

Lisa Fay, EIS Project Manager
MDNR Division of Ecological and Water Resources
Environmental Review Unit
500 Lafayette Road, Box 25
St. Paul, MN 55155-4025

Please contact any of the following if you have any questions about the environmental review process:

Lisa Fay, MDNR at 651-259-5110
Douglas Bruner, USACE at 651-290-5378
Michael Jiménez, USFS at 218-626-4383

Members of the media may contact any of the following with questions:

Chris Niskanen, DNR communications director, 651-259-5023, chris.niskanen@state.mn.us
Patrick Moes, public affairs officer, U.S. Army Corps of Engineers, 651-290-5202, patrick.n.moes@usace.army.mil
Kristina Reichenbach, public affairs officer, Superior National Forest, 218-626-4393, kreichenbach@fs.fed.us

Questions about the proposed project may be directed to:

Jennifer Saran, PolyMet Mining, Inc., 444 Cedar Street #2060, St. Paul, MN 55101, 651-389-4108

ERRATA SHEET
Final Environmental Impact Statement
PolyMet Mining, Inc. – NorthMet Mining Project and Land Exchange
November 24, 2015

Item 1: Addition to Final EIS Master Reference List

The text on Final EIS Page REF-11 is edited to read:

--- 2015m. *Zim Wetland Mitigation Site Hydrology Monitoring, 2012-2014*. Prepared for PolyMet Mining, Inc. April 2015.

---2015n. Technical Memorandum: *Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 4*. From Tina Pint and Jere Mohr to Bill Johnson, MDNR. September 14, 2015.

Barr (Barr Engineering) and HC Itasca. 2009. *Dissolved Solids and Chemical Balance – Mesabi Nugget Phase II Project*. Draft 01. Prepared for Steel Dynamics, Inc. Mesabi Mining, LLC. by Barr Engineering and HC Itasca. December 14, 2009.

Item 2: Edits to Select Final EIS Text

The text on Final EIS Page 5-240, top of page, is edited to read:

…resources. However, its effectiveness at the NorthMet site is uncertain and it may need to be combined with other mitigation options (Barr 2015~~b~~n).

The text on Final EIS Page 5-242, top of page, is edited to read:

...operations. The trench may only need to operate in non-frozen conditions to supply sufficient water to create a bedrock groundwater mound (Barr 2015~~b~~n).

Item 3: Correction to Final EIS Reference Document

The following document is the correct reference to the Final EIS:

Barr Engineering. Technical Memorandum: *Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 4*. From Tina Pint and Jere Mohr to Bill Johnson, MDNR. September 14, 2015.

See Attachment 1. 25 pages.

Item 4: Addition to Final EIS Master Reference List

The text on Final EIS Page REF-44 is edited to read:

---1998. *A Spatial Assessment of Hydrologic Alteration within a River Network*. Regulated Rivers: Research & Management, 14: 329-340.

Richter, B.D., M.M. Davis, C. Apse, and C. Konrad. 2011. Short Communication: A Presumptive Standard for Environmental Flow Protection. River Research and Applications (2011). Wiley Online Library.

Rio Tinto (Rio Tinto plc). 2010. Fact Sheet: Nickel-Copper Exploration Target at Tamarack (Minnesota, USA). Retrieved from: http://www.riotinto.com/documents/ReportsPublications/Nickel Copper exploration target at Tamarack.pdf.

Rio Tinto (Rio Tinto plc). 2010. Fact Sheet: Nickel-Copper Exploration Target at Tamarack (Minnesota, USA). Retrieved from: http://www.riotinto.com/documents/ReportsPublications/Nickel Copper exploration target at Tamarack.pdf.

See Attachment 2. Ten (10) pages.

ERRATA SHEET –ATTACHMENT 1
Final Environmental Impact Statement
PolyMet Mining, Inc. – NorthMet Mining Project and Land Exchange
November 24, 2015

Barr Engineering. Technical Memorandum: *Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 4*. From Tina Pint and Jere Mohr to Bill Johnson, MDNR. September 14, 2015. 25 pages.

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Technical Memorandum

To: Bill Johnson, Minnesota Department of Natural Resources
From: Tina Pint and Jeré Mohr
Subject: Response to Cooperating Agency Comments Related to Peter Mitchell Pit – Version 4
Date: September 14, 2015
Project: NorthMet EIS (23690862.00)
c: Jennifer Saran, Poly Met Mining Inc.

This memorandum addresses comments and questions raised by the Cooperating Agencies related to the potential for groundwater flow from the proposed NorthMet pits north to the Peter Mitchell Pits (PMP) after closure of both mines.[1]

This memorandum focuses on two key points regarding the conceptual model for groundwater flow in bedrock at the NorthMet Mine Site:

1. Based on historic conditions at Peter Mitchell pits, regional information from taconite operations on the Mesabi Iron Range, and professional judgment, it was determined that future mine pits (NorthMet) or mine pits expansions (Peter Mitchell) should not cause significant drawdown in the bedrock units. That determination, in conjunction with the distance between the two mine sites, led to the conclusion that the conceptual model for the NorthMet Project environmental impact statement should not include the potential for groundwater flow north from the NorthMet pit to the PMP. Information on historic conditions at Peter Mitchell pit are discussed in Section 2.1 and Section 2.2, and other regional information is presented in Section 2.3.

2. The determination that groundwater is unlikely to flow from the NorthMet pit to the PMP is further supported by ongoing monitoring of water levels in bedrock at the proposed NorthMet mine site during different stages of mine pit development at Peter Mitchell (presented in Section 3.1), and the results from site-specific aquifer tests (presented in Section 3.2). Based on a review of recent aerial photographs and water appropriations permit pumping records, significant dewatering began in a portion of the Peter Mitchell pit complex near the NorthMet Mine Site in approximately 2003. Water elevation data from NorthMet bedrock wells indicates that this dewatering has not caused a drop in water levels in bedrock at the NorthMet mine site. This data strongly supports the conceptual model that future dewatering and long-term conditions at Peter Mitchell pit will not significantly affect groundwater flow directions at NorthMet.

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[1] Closure of the NorthMet Mine is anticipated to occur in approximately 2040. Closure of the Northshore Mine is anticipated to occur in 2070.

Even though northerly groundwater flow is not reasonably foreseeable, PolyMet has committed to monitoring water levels in bedrock between the NorthMet Mine Site and Peter Mitchell during operations, reclamation, and long-term closure to confirm the conceptual model. Proposed monitoring locations are discussed in Section 4.2; details on specific monitoring requirements will be determined in permitting. A number of adaptive management options to prevent northerly flow of groundwater are available if future monitoring suggests such flow to the north could occur (see Section 4.2). A list of possible options are as follows:

- control the water level in the West Pit via pumping to insure gradients are inward
- maintain a groundwater mound between the PMP and NorthMet pits by injecting water via wells
- maintain a groundwater mound between the PMP and NorthMet pits by constructing an infiltration trench
- grout fractures in the NorthMet pits to minimize outflow

1.0 Background Data on Peter Mitchell Pits and NorthMet Pits

The information presented in this section provides background on the physical settings of the Peter Mitchell and NorthMet Pits. Large Figure 1 shows the Peter Mitchell Pit areas near the NorthMet project area. Large Figure 2 shows the long-term plan for the Peter Mitchell Pits. In this document, the names used for the Peter Mitchell Pit areas generally follow the naming used by Northshore Mining. Table 1 summarizes the estimated pit bottom and water surface elevations at the NorthMet and Peter Mitchell pits over time.

Table 1 Mine Pit Elevations

	NorthMet Pit Elevations (feet MSL)				Peter Mitchell Pit Elevations (feet MSL)(1)			
	West Pit		East Pit		Area 003 West(2)		Area 003 East(2)	
Period	Ground Surface	Water Surface	Ground Surface	Water Surface	Ground Surface	Water Surface	Ground Surface	Water Surface
Existing	1600	--	1600	--	1530-1580(3)	1624	1530	1568
Maximum Extent of Mining	940	--	920	--	1360-1380(3)	--	1360	--
Long Term (post 2080)	940	1576	1589(4)	1592	1360-1380(3)	1500	1360	1500

(1) Reference (1)
(2) PMP Area 003 West and Area 003 East refer to areas identified in Large Figure 1
(3) PMP Area 003 West consists of two interconnected pit areas with different bottom elevations
(4) Top of East Pit backfill
-- Pit is dewatered

Geologic cross sections through the Peter Mitchell pits and the NorthMet pits, locations of which are shown on Large Figure 1, are detailed in Large Figure 3 and Large Figure 4. These cross-sections show both existing conditions and maximum extents of both the Peter Mitchell pits and the NorthMet pits. At their maximum extent, the Peter Mitchell pits will remain approximately 6,500-8,000 feet (1.2 – 1.5 miles) north of the NorthMet mine pits, and will be approximately 400 feet MSL shallower.

2.0 Data Used to Inform the Conceptual Model

2.1 Peter Mitchell Pit Historic Levels

Water levels in the Peter Mitchell pits are considered surface expressions of the water table in the vicinity of those pits. Information on historical water levels in the various Peter Mitchell pits were used to help inform expected conditions during future operations. Limited public information is available on the water levels within the Peter Mitchell pits. To estimate water levels in portions of the Peter Mitchell pits over time, a combination of aerial photography and topographic data sets (including contour data and LiDAR data) was used. Water levels were estimated for two portions of the Peter Mitchell pits, referred to herein as Area 003 West and Area 003 East (Large Figure 1). The results of this analysis are summarized in Table 2.

Table 2 Approximate Historic PMP Water Levels

Year	Data Sources Used	Approximate PMP Water Level (feet MSL)	
		Area 003 West	Area 003 East
1991	Aerial + 1996 contours[1] + LiDAR	1622	1623
1998	Aerial + 1996 contours[1] + LiDAR	1620	1620
2006	Aerial + 1996 contours[1] + LiDAR	1624	1602
2008	Aerial + 1996 contours[1] + LiDAR	1625	1582
2009	Aerial + 1996 contours[1] + LiDAR	1625	1570
2010	Aerial + LiDAR	1623	< 1568
2011	LiDAR data	1622	1568
2013	Aerial + LiDAR	1624	< 1568

(1) Contour interval for 1996 contours is 5 feet

Pumping records for the water appropriation permits associated with the Peter Mitchell pit were also assessed. There was no water appropriated from the Area 003 West pits since at least 1988 (the first year electronic water use data is available). Since 2003, water has been appropriated from the Area 003 East pits (excluding 2005) at a nearly constant level (reported water usage obtained for Water Appropriation Permit 1982-2097 – 3 from http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html). This is consistent with the drop in water level observed in the aerial photos between 1998 and 2006.

Since 1991, water levels in the Area 003 West pits have remained relatively constant. It is unclear from aerial photography whether a surface connection currently exists between the two pit areas within Area 003 West, but water levels between the two areas have remained similar. Water levels in the Area 003 East pits have decreased since the late 1990s to less than 1568 feet MSL (the lowest visible contour based on the 2011 LiDAR data) since 2010. If there were a substantial cone of depression associated with Area 003 East pit dewatering, it would be reasonable to expect at least some water level response in Area 003 West, since these two pits are separated by approximately 500 feet at their closest point. No water level response in Area 003 West is apparent.

These observations indicate that the hydraulic conductivity of the Biwabik Iron Formation in the vicinity of the Peter Mitchell pits is low enough to support the large observed pit stages differences noted above. Based on the fact that PMP pits as close as 500 feet show no significant hydraulic connectivity, it is reasonable to conclude that the dewatering and long term closure of the PMP is unlikely to cause lowering of groundwater elevations large distances from the PMP site.

Although the Biwabik Iron Formation is utilized by some Iron Range communities as a water supply, regional information indicates that the formation has relatively low hydraulic conductivity in the area of the Peter Mitchell pits. Reference (2) indicates that "The Biwabik Iron-Formation lies about 3 miles south of Babbitt, but it is not an important aquifer in this area. Highly permeable leached ore bodies are not present east of Mesaba because of the thermal metamorphism by the intrusives of the Duluth Gabbro Complex (Reference (3)). Consequently, the permeability of the iron-formation is low, and ground-water movement through the formation is confined to narrow joints and fractures.

2.2 Lakes near Peter Mitchell Pit

Two lakes are located less than one mile northwest of the Peter Mitchell pits and overlie the Biwabik Iron Formation (the same formation mined at Peter Mitchell): Iron Lake and Argo Lake. Increasing lake water levels observed at these lakes from 1946 to 1980 during mining at Peter Mitchell, combined with the lakes' likely connection to bedrock, strongly suggest that the impact of the Peter Mitchell pits on the bedrock groundwater levels is limited, even in close proximity to the pits.

Iron Lake is approximately 170 acres in size with water surface elevation of around 1760 feet MSL and a maximum depth of about 20 feet. The MGS bedrock elevation GIS dataset estimates the top of bedrock elevation below Iron Lake ranges from 1740 to 1760 feet MSL. The metadata associated with this dataset indicates that the bedrock elevations have an approximate vertical accuracy of +/- 20 feet (Reference (4)). As the maximum lake depth is 20 feet, portions of the lake bottom are likely exposed to bedrock. In addition, a geologic map of the area surrounding Iron Lake shows bedrock outcrops immediately adjacent to the lake along several areas of the shoreline (Reference (5 p. Plate XVI)).

Argo Lake, located northeast of Iron Lake, is about 80 acres in size with a water surface elevation of about 1745 feet MSL. The MGS dataset estimates the top of bedrock below Argo Lake to be between 1700 and 1750 feet MSL. Although the bathymetry of Argo Lake is unknown, the bedrock elevation is approximately equal to the ground elevation along the northwest side of the lake and the regional bedrock map indicates bedrock outcrops along the northern and northeastern shorelines of the lake (Reference (6)), suggesting that at least some portion of the lake bottom is likely connected to bedrock.

Water level data are available for Iron and Argo Lakes from 1946 to 1980. Mining activities at Peter Mitchell commenced in the mid- to late 1950s and have been ongoing since that time. During that time, water levels in Iron Lake and Argo Lake have fluctuated within a 6.3 foot range and a 7.1 foot range, respectively (Figure 1). These ranges are relatively small for lakes without controlled outlets in a region with a net precipitation of approximately 11 inches per year.

Over the 30 year period from 1950 to 1980, the water level in both lakes has gradually increased by 2 to 3 feet. Based on 2011 LiDAR data, the elevation of Iron Lake (1760.2 feet) is 4 feet greater than observed in

1946. The estimated 2011 elevation of Argo Lake is 1745.1 feet, although the relative change from 1946 is unknown due to the use of a local datum from 1946 through 1980. The increase in water levels over time is likely due to the regional net precipitation of approximately 10+ inches and the fact that the lakes are landlocked. The gradual increases in lake water levels at elevations well above those of the nearby Peter Mitchell pits suggest that the nearby dewatering activities in the pits have not had a significant effect on the stages of the lakes. As with the observations of pit stage variations at PMP, the information on Iron Lake and Argo Lake indicates that the dewatering and closure of the PMP will not cause lowering of groundwater elevations at distances of less than one mile from the PMP site.

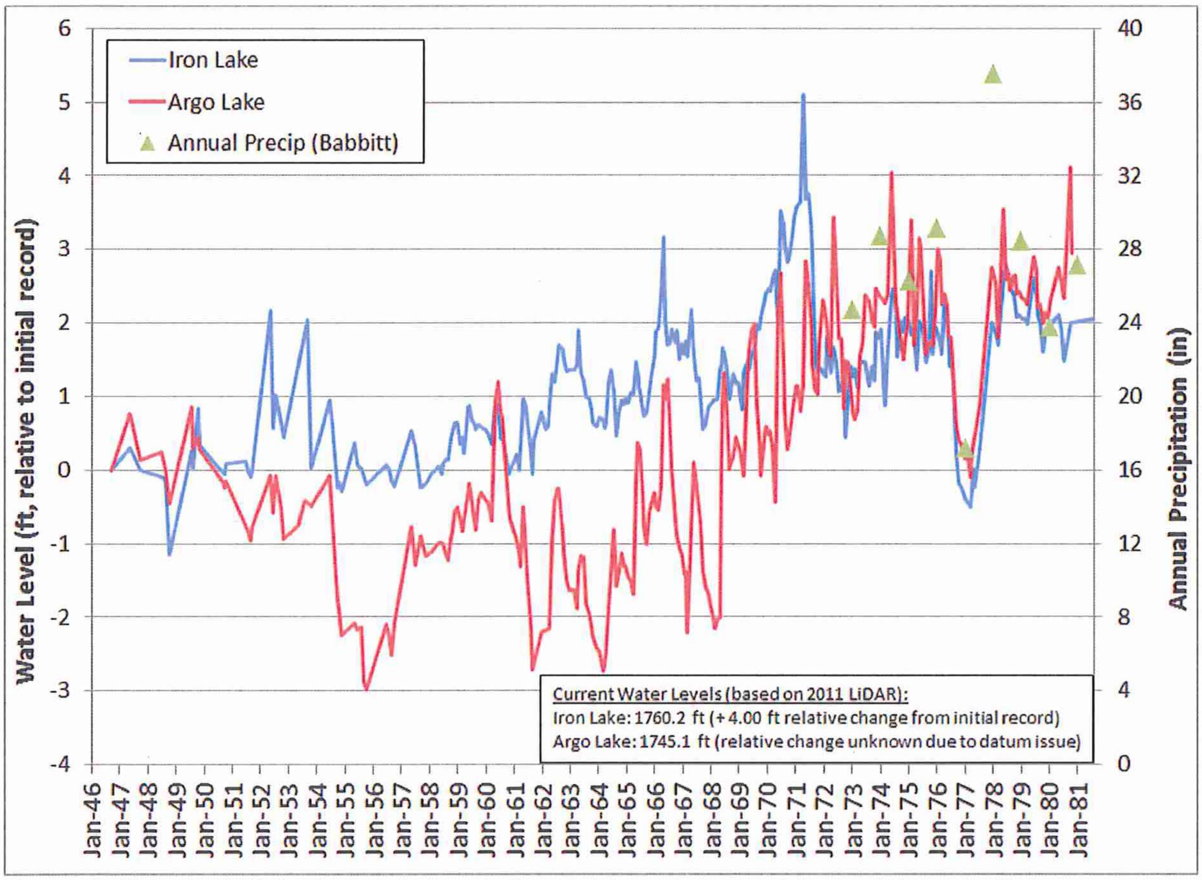
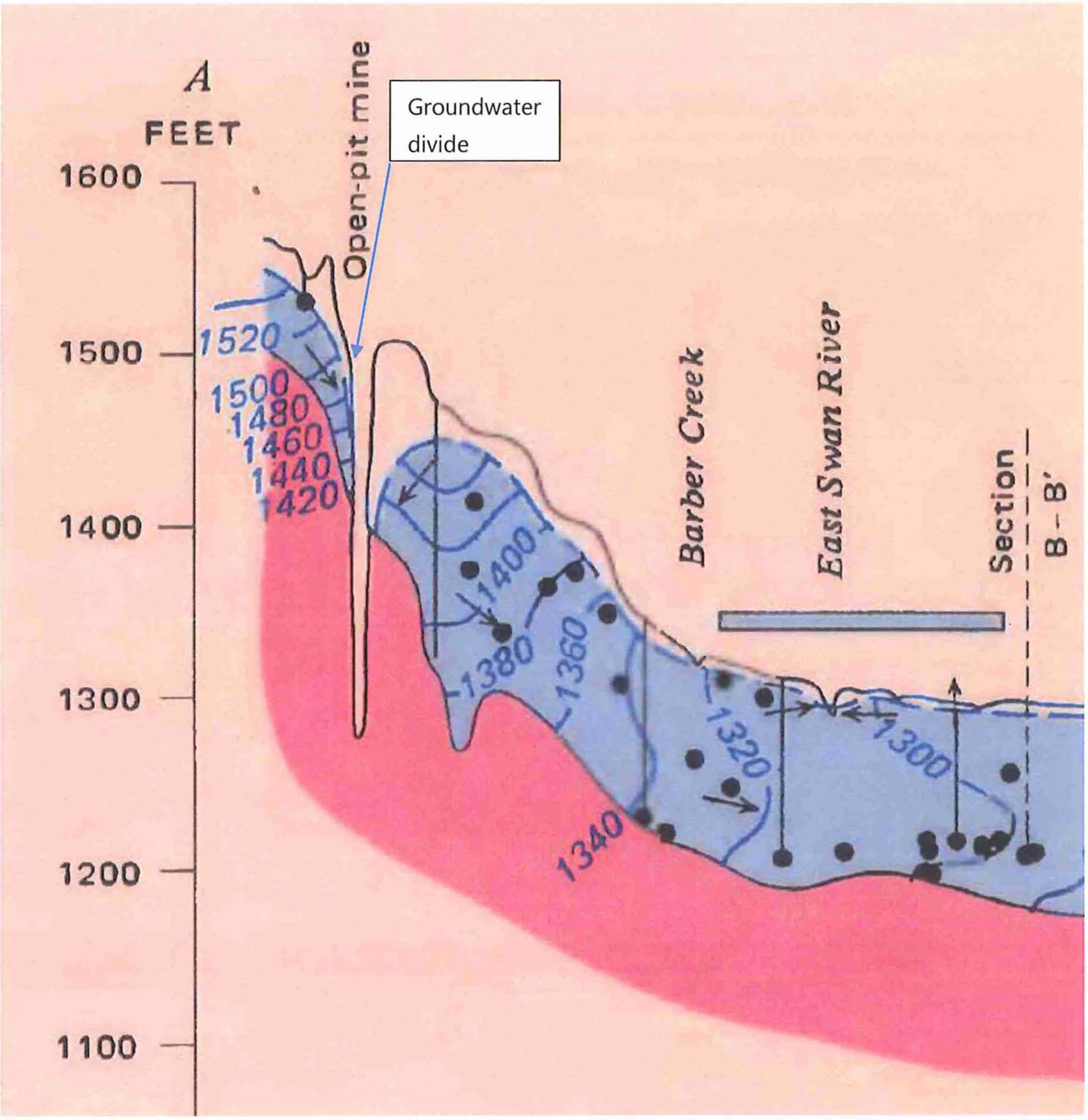


Figure 1 Historical Water Levels in Iron Lake and Argo Lake and Annual Precipitation

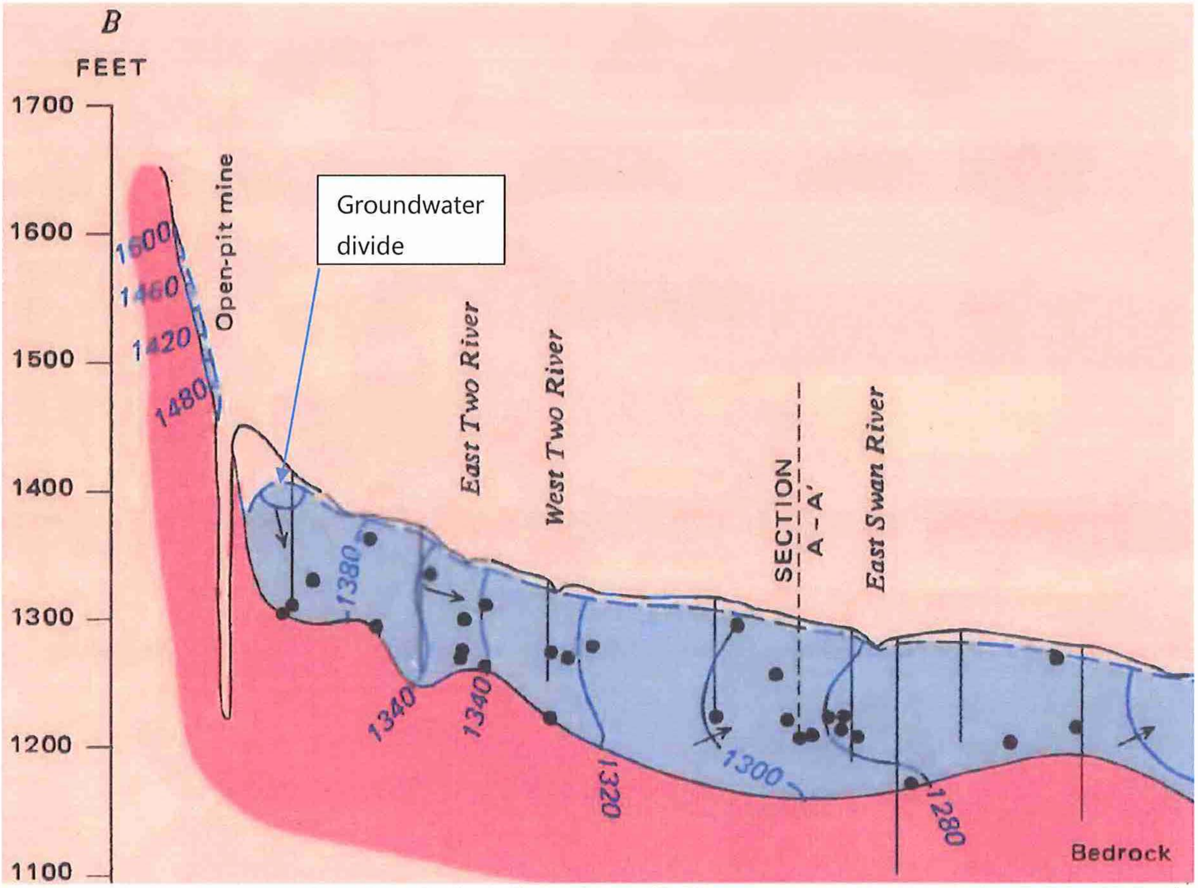
2.3 Regional Data from the Mesabi Iron Range

Historic evidence from the PMP and other open pits on the Iron Range further supports the conclusion that groundwater flow between the PMP and the NorthMet pits is unlikely, and that it is reasonable to expect that a groundwater mound between the two pits will be maintained. While local variability is expected, the geologic setting and characteristics of the sites discussed below are sufficiently similar to the area near NorthMet and PMP that the findings of these studies are useful in informing the expected groundwater flow directions in the area between NorthMet and PMP. Although bedrock water level data are limited, experience with open pit mining on the Iron Range has shown that the impacts from dewatering pits are realized locally, or within close proximity (within approximately 1500 feet) to the pits. For example, Figure 2 and Figure 3 show groundwater divides are inferred in the surficial aquifer within close proximity to open mine pits located near Chisholm and Eveleth (Reference (7)).



From Cross-section A-A' of Reference (7). *The portion shown has a length of approximately 17 miles*

Figure 2 Portion of a Cross Section Showing Hydraulic Head Contours in the Drift Aquifer Adjacent to an Open-pit Mine



From Cross-Section B-B' of Reference (7). *The portion shown has a length of approximately 22 miles*

Figure 3 Portion of a Cross Section Showing Hydraulic Head Contours in the Drift Aquifer Adjacent to an Open-pit Mine

A hydrologic assessment in the Hibbing area showed similar results. Reference (8)indicates that in the Hibbing area, the groundwater divide in the surficial aquifer north of the mined areas still coincided with topographic divides. South of the mined areas, the groundwater divide in the surficial aquifer was estimated to be located within a few hundred to approximately 2000 feet of the mine pits and to range in elevation from approximately 1520 to greater than 1460 feet MSL adjacent to pits in which the water levels ranged from 1100 to 1175 feet MSL.

The East Range Hydrology Study focused on taconite mine pits in the Hoyt Lakes area and concluded that groundwater inflow to the pits was predominantly from surficial sources (Reference (9)). In addition, regarding refilling of mine pits following dewatering, the authors concluded that substantial groundwater outflow will not occur until the pit stage exceeds the lowest down-gradient water table elevation in the adjacent surficial deposits. These two observations support the concept that flow to a large pit with a low stage such as the existing and future Peter Mitchell pit would likely produce some water from seepage from the surficial deposits (limited by desaturation in the vicinity of the pit), and minimal groundwater flow from the bedrock, limited by the reduced saturated thickness in the vicinity of the pit. At Peter Mitchell, groundwater flow would be further limited by the lower hydraulic conductivity of the rock types that exist between the PMP and the NorthMet site.

The examples described above show that the hydrologic impacts from pit dewatering on the Iron Range are realized locally, or within close proximity to the pits. Because of this, it is reasonable to conclude that neither dewatering at the Peter Mitchell pits, nor the long-term closure plan for the pit, will have hydrologic impacts at the site of the future NorthMet pit.

2.4 Conclusion

All of the information above was known and available when the Co-leads developed the conceptual model for the PolyMet project. In summary: (1) Observations of water levels in the PMP show that hydraulic conductivity of the Biwabik Iron Formation in the vicinity of the Peter Mitchell pits is low, to the point that even pits as close as 500 feet do not show significant hydraulic connectivity. (2) Increasing water levels at two lakes less than one mile from the PMP—during active mining at the PMP—further demonstrate low groundwater connectivity. (3) Historic data shows that hydrologic impacts from pit dewatering are realized only within close proximity to the pits. For all of these reasons, it was reasonable to conclude as part of the PolyMet project conceptual model that groundwater would not flow north from the PolyMet pit to the PMP. Accordingly, it was not necessary to evaluate changing PMP levels in the Mine Site MODFLOW model that was used to perform certain impacts analyses for the NorthMet Mine Site.

3.0 Validation of the Conceptual Model

3.1 Site Groundwater Elevation Data

Water levels in NorthMet bedrock wells do not show a response to dewatering activities at Peter Mitchell. Water levels have been measured in five bedrock observation wells from 2007 to present. Wells OB-1 and OB-2 (shown on Large Figure 1) are completed in the Duluth Complex, while the remaining three wells are completed in the Virginia Formation. All five wells are 100 feet deep. Figure 4 shows groundwater elevation trends in these five wells compared with pit stages in the Peter Mitchell East Pit. The lack of response in the observation wells during a period of dewatering at the Peter Mitchell East Pit provides recent, direct evidence to support the conclusion that water levels in the PMPs do not have an effect on bedrock water levels at the NorthMet site.

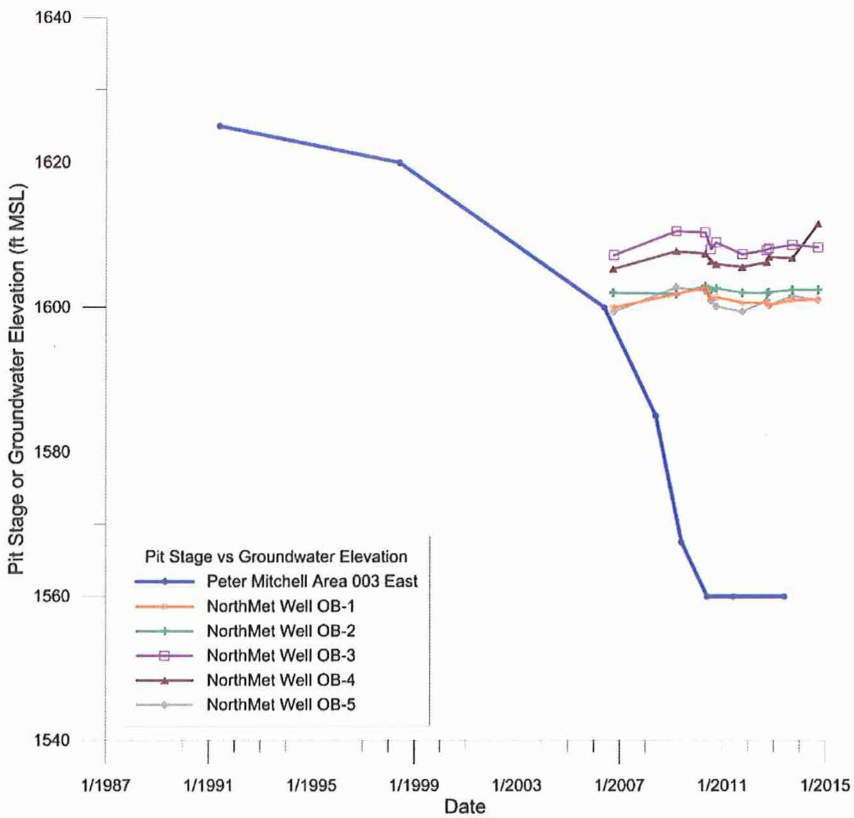


Figure 4 Plots of Groundwater Elevations in Bedrock Wells at the PolyMet Site and Stage in the Peter Mitchell East Pit

3.2 NorthMet Site-Specific Aquifer Testing

Pumping tests were completed at the Mine Site during the Phase II and Phase III Hydrogeologic Investigations conducted in 2005 and 2006 (Reference (10), Reference (11)). During the Phase II Hydrogeologic Investigation, tests were completed in four pumping wells (P-1 through P-4) completed in the Virginia formation, and water levels were monitored in bedrock observation wells (Ob-1 through Ob-5 and a preexisting water supply well). With the exception of Ob-2, which was installed in the Duluth Complex, all the observations wells were completed in the Virginia Formation. Pumping test durations ranged from 35 to 96 hours. During the Phase III Hydrogeologic Investigation, a 30-day pumping test was conducted in well P-2. The majority of the observation wells during this test were installed in the wetland deposits in the wetland north of P-2; however, water levels were also monitored in Ob-2.

The observed drawdowns in the pumping wells and observation wells during the pumping tests are summarized in Table 3 and shown on Large Figure 5. They indicate minimal propagation of drawdown within the bedrock due to its low transmissivity. For example, drawdown at wells P-1, P-2, and P-4 on the order of tens to hundreds of feet resulted in little to no observed drawdown in bedrock observation wells within a few hundred feet of the pumping wells. Drawdown in observation wells near P-3 was somewhat higher than other locations but, at most, was approximately half the maximum drawdown at the pumping well at a distance of 108 feet from the pumping well.

Hydraulic conductivity estimates from the Phase II pumping tests ranged from 0.0024 feet/day to 1 foot/day, with a geometric mean value of 0.17 feet/day. The low hydraulic conductivity of the Virginia Formation is expected to reduce the propagation of drawdown away from the PMP as the influence of the low stage in the pit spreads south at similar elevations to the pit walls. In addition, as the influence of groundwater inflow to the PMP spreads down-dip in the Biwabik Iron Formation, the high resistance to vertical flow through the Virginia Formation (because the Virginia Formation is a metasedimentary unit that likely have some degree of horizontal stratification) is expected to limit the influence on shallower units.

The fact that aquifer tests at the NorthMet site show minimal drawdown at distances as close as 115 feet further bolsters the conceptual model that changes in PMP water levels—which occur at least 6,500 feet away from the future NorthMet pit—will not cause northerly groundwater flow.

Table 3 Summary of Aquifer Tests Performed at the NorthMet Site

Hydrogeologic Investigation	Pumping Well	Average Pumping Rate (gpm)	Pumping Duration	Observation Well	Observation Well Distance from Pumping Well, feet MSL	Pumping Well Maximum Drawdown, feet MSL	Observation Well Maximum Drawdown, feet MSL
Phase II Hydrogeologic Investigation	P-1	1.5	36 hr	Ob-1	310	324.10	<0.1
	P-2	28	36 hr	Ob-2	274	258.04	4.57
	P-3	40	96 hr	Ob-3	115	41.09	8.66
				Ob-3a	108	41.09	23.22
				Water Well	330	41.09	16.73
	P-4	39	35 hr	Ob-4	1370	36.90	<0.1
				Ob-5	245	36.90	<0.2
Phase III Hydrogeologic Investigation	P-2	22	30 days	Ob-2	274	221.71	4.85

4.0 Adaptive Water Management

4.1 Approach

For the reasons discussed above, the work done to support the FEIS appropriately analyzes the potential environmental effects of reasonably foreseeable activities within the NorthMet Project. Those reasonably foreseeable effects do not include groundwater flow to the north through bedrock, which is highly unlikely to occur. Similarly, because mitigation measures designed to address northerly groundwater flows are highly unlikely to be needed, they also do not constitute reasonably foreseeable actions.

By proactively monitoring its environmental controls and the environmental setting, PolyMet can continuously evaluate environmental impacts. PolyMet will analyze monitoring information and use adaptive management practices[2], as needed, along with associated mitigations, to prevent significant adverse effects. These tools, which are consistent with industry standard practice, have been used throughout PolyMet's environmental review process, and will continue to be used in permitting, operations, reclamation, and long-term closure.

The following sections describe PolyMet's use of monitoring and adaptive management as applied to assessing and addressing the potential for groundwater flow to the north. With early implementation of this monitoring plan, PolyMet will be able to collect and analyze hydrology data in a timely manner. If the data show it is necessary, adaptive management can be employed. Three feasible mitigation measures are outlined below, that could be used separately or in combination with each other, to adequately address any concern that arises.

4.2 Monitoring

PolyMet will monitor groundwater flow through use of proposed bedrock monitoring locations north of the NorthMet mine pit, which are shown on Large Figure 6. While final details on the number and locations of wells will be determined in permitting, PolyMet currently proposes eight wells for the area between the PolyMet NorthMet pits and the Peter Mitchell pits. Two of these wells (the eastern most and the one between the Category 1 waste rock stockpile and the West Pit) are existing wells. The locations of the new wells have been subject to preliminary evaluation by the co-lead agencies. All eight wells will provide key data during operations on the water level in bedrock to help address the question of whether there is the potential for flow between the two mine sites. Four additional bedrock wells are proposed in the area south of the West Pit and the Category 2/3 Waste Rock stockpile for other monitoring purposes. New monitoring wells would be installed prior to operations, which would allow for more than 10 years of water level monitoring prior to any potential for northerly flow (note that northerly flow out of the

[2] *Theodore Roosevelt Conserv. P'ship v. Salazar*, 616 F.3d 497, 517 (D.C. Cir. 2010).

NorthMet pits is only possible once the NorthMet pits start to be backfilled and flooded, which begins in Year 11 for the East Pit).

4.3 Potential adaptive management options

If conditions observed in these northerly wells are not as expected, and a groundwater divide is not maintained between the PMP and NorthMet project areas when needed to prevent flow to the north, PolyMet will be able to implement adaptive management practices to prevent northward flow. This Section outlines three feasible and efficacious adaptive management measures that PolyMet could implement should the need arise.

4.3.1 West Pit Water Level Suppression

The first option for adaptive management would be to manage the NorthMet pit water levels via pumping to keep the West Pit stage below dewatering level at Peter Mitchell when there is active mining at Peter Mitchell, and below the Peter Mitchell pit lake level thereafter. This practice would result in a long-term pit lake level in the West Pit below 1,500 feet MSL, compared to the currently planned level of 1,576 ft MSL. Water pumped from the pit would be sent to the WWTF and discharged similar to the current plan for West Pit closure.

Water levels in the East Pit would be maintained near an elevation of 1,592 feet MSL so that the backfilled waste rock in the pit remains inundated. Water from the East Pit will flow into the West Pit because of the close proximity between the East and the West pits and because the water level in the West Pit will be below the water level at Peter Mitchell. The resulting hydraulic gradient between the East Pit and the West Pit will be larger than a gradient between the East Pit and the Peter Mitchell Pit. Therefore, water will flow from the East Pit to the West Pit, rather than north toward Peter Mitchell. If needed and based on environmental conditions at some future point, this management option could be combined with other adaptive management practices such as bedrock water level maintenance (see Section 4.3.2) or pit wall grouting to reduce the hydraulic conductivity of a portion of the Virginia Formation (see Section 4.3.3) to further reduce the potential for flow to the north.

This management practice will both be effective at addressing any unforeseen groundwater flow to the north and is technically feasible. While keeping the West Pit water level lower may result in more exposed wall rock load generation, under the current project plans, the water that is pumped from the West Pit is routed to the WWTF to be treated prior to discharge. Based on the current MODFLOW model predictive simulations, groundwater inflow to the West Pit at an elevation of 1,500 feet MSL is expected to be approximately 50 gpm, approximately 10 gpm greater than the expected groundwater inflow at the currently-planned long-term elevation of 1,576 feet MSL. The WWTF, as currently designed, will be sufficient to handle this increase, particularly as the existing plans for the WWTF at closure involve upgrading the plant from a chemical precipitation plant to a reverse osmosis treatment plant. Therefore, this adaptive management practice will allow PolyMet to fully address any unanticipated groundwater flow to the north and, if needed, will be refined and reviewed by the relevant agencies based on the available data consistent with the NPDES/SDS permit and Permit to Mine programs.

4.3.2 Bedrock Water Level Maintenance

A second feasible option for adaptive management would be to maintain a water level in bedrock north of the NorthMet mine pits that is higher than the long-term water level planned for the pits (shown in Table 1) by artificial recharge. Water level control via infiltration or injection is a proven technology that has been used successfully on other project sites to mitigate hydrologic impacts associated with mine pit dewatering. Rubio and Fernandez (Reference (12)) presents a high level overview of the use of artificial recharge of groundwater in mining, and includes examples of mines that have successfully used infiltration and injection to minimize the effects of mine dewatering at copper, gold, and iron mines across the globe. One example is at the Garzweiler Lignite Mines in Germany, where a combination of surface trenches and injection wells are used to maintain water levels in the various bedrock and surficial units to minimize impacts to nearby wetlands. Huxley et al. provides additional case studies on how recharge features have been successfully used to mitigate the impacts of quarry dewatering (Reference (13)). Injection wells are also commonly used to create barriers to salt water intrusion (Reference (12), Reference (13)). Here in Minnesota, Unimin Corporation conducted a pre-mining field test to evaluate a water level mitigation system to prevent mine dewatering drawdown from impacting calcareous fen wetlands near their Kasota mine in Le Sueur County, Minnesota (Reference (14)). The results of this field test demonstrate that artificial recharge is an effective method of maintaining a higher volume of water in targeted areas in Minnesota's environmental setting.

At NorthMet, an application of this industry-proven method for preventing flow to the north would be to construct an infiltration trench on the north side of the Category 1 Waste Rock Stockpile, extending east along the north side of the cut-off dike, and to the eastern extent of the East Pit. This water-filled trench would extend to bedrock and could have water levels maintained using, among other potential water sources, stormwater runoff from the covered Category 1 Waste Rock stockpile and treated water from the WWTF.

The available water sources should be adequate for this recharge method for two reasons. First, the bedrock has relatively low permeability in this area and only minimal amounts of water would be required to maintain a mound. Screening level analysis conducted by the Co-lead Agencies suggests that approximately 160 gpm would need to be infiltrated or injected in order to maintain a groundwater mound within bedrock (Reference (14)). Second, given the slow velocities for groundwater flow in bedrock (estimated to be 15-30 ft/yr), the infiltration trench would only need to operate during non-frozen conditions. Therefore, stormwater from the Category 1 stockpile would alone provide a sufficient volume of water to recharge the bedrock. The estimated flow of 160 gpm is equivalent to approximately 5.9 inches per year over the Category 1 Waste Rock Stockpile, which is less than the anticipated stormwater yield available for infiltration (estimated to be 8.5 inches per year with the geomembrane cover).

If the water supply from this water sources is inadequate to maintain water levels in the trench, other water sources would provide a sufficient supply of water. These water sources include treated water from the Wastewater Treatment Plant (WWTP), water retained in a basin, and injection wells in place of, or to supplement the infiltration trench. Based on a preliminary evaluation using the measured properties of the bedrock and the estimated injection rate of 160 gpm, it is expected that between 10 and 50 wells would be needed, with the actual number dependent on localized hydraulic conductivity and depth to the water table. Therefore, in the unlikely event that future monitoring identifies a northerly flow from the NorthMet mine pits, PolyMet will have available sufficient water volume and a combination of options (infiltration trench and injection wells) to recharge the bedrock north of the pits to prevent this flow.

4.3.3 Pit Wall Grouting

A third feasible adaptive management practice that would be effective, alone or in combination with one of the preceding options, is implementation of the Conceptual Plan for Bedrock Groundwater Flow Mitigation (Reference (15)) that PolyMet has outlined. Industrial mining grout (commonly a mixture of bentonite, cement and water) injection can be used to seal or close fractures and faults, which then controls bedrock groundwater flow to and from mine pits. Also, grout curtains can be used for groundwater control in both unconsolidated deposits and fractured rock. A grout curtain is constructed by drilling a series of purposely spaced and oriented bedrock drill holes and injecting grout into the surrounding rock to fill pore spaces, fractures and faults.

Use of grout to control water at mine sites is a widely used and proven mitigation measure. Powers et al. present an overview of grouting methods and applications for groundwater control (Reference (15)) Additional mining applications are presented in Reference (16), Reference (17), and Reference (18). At the NorthMet Mine Site, if appreciable bedrock flow into the pits were to unexpectedly occur, it will be readily apparent as the pits are deepened during mining. At that stage, PolyMet will have the necessary information about site conditions to coordinate with the appropriate agencies and grout those features (fractures, faults) down to the projected maximum depth of the final Peter Mitchell pits before the NorthMet pits are flooded. By grouting to this depth before pit flooding, PolyMet will guard against unexpected northerly flows from the flooded pit toward the Peter Mitchell pits.

4.4 Conclusion

Because the primary purpose of adaptive management is to address unpredicted developments by monitoring the actual effects of a project, it is sufficient under NEPA that such "mitigating measures are described in general terms and rely on general processes."[3]

As part of the permitting process for the NorthMet Project, PolyMet will continue to refine and develop new monitoring and mitigation plans. PolyMet anticipates that the NPDES/SDS permit issued by MPCA will include enforceable conditions regarding monitoring and, if necessary, mitigation of northerly groundwater flow. Through the NPDES/SDS permitting program and the annual reporting requirement under the Permit to Mine, the MDNR and MPCA would have access to the necessary information regarding actual environmental conditions, which will allow those agencies and PolyMet to effectively evaluate the information, and determine the need for mitigation. Adaptive management is an important tool that PolyMet will continue to use during, operations, reclamation, and long-term closure.

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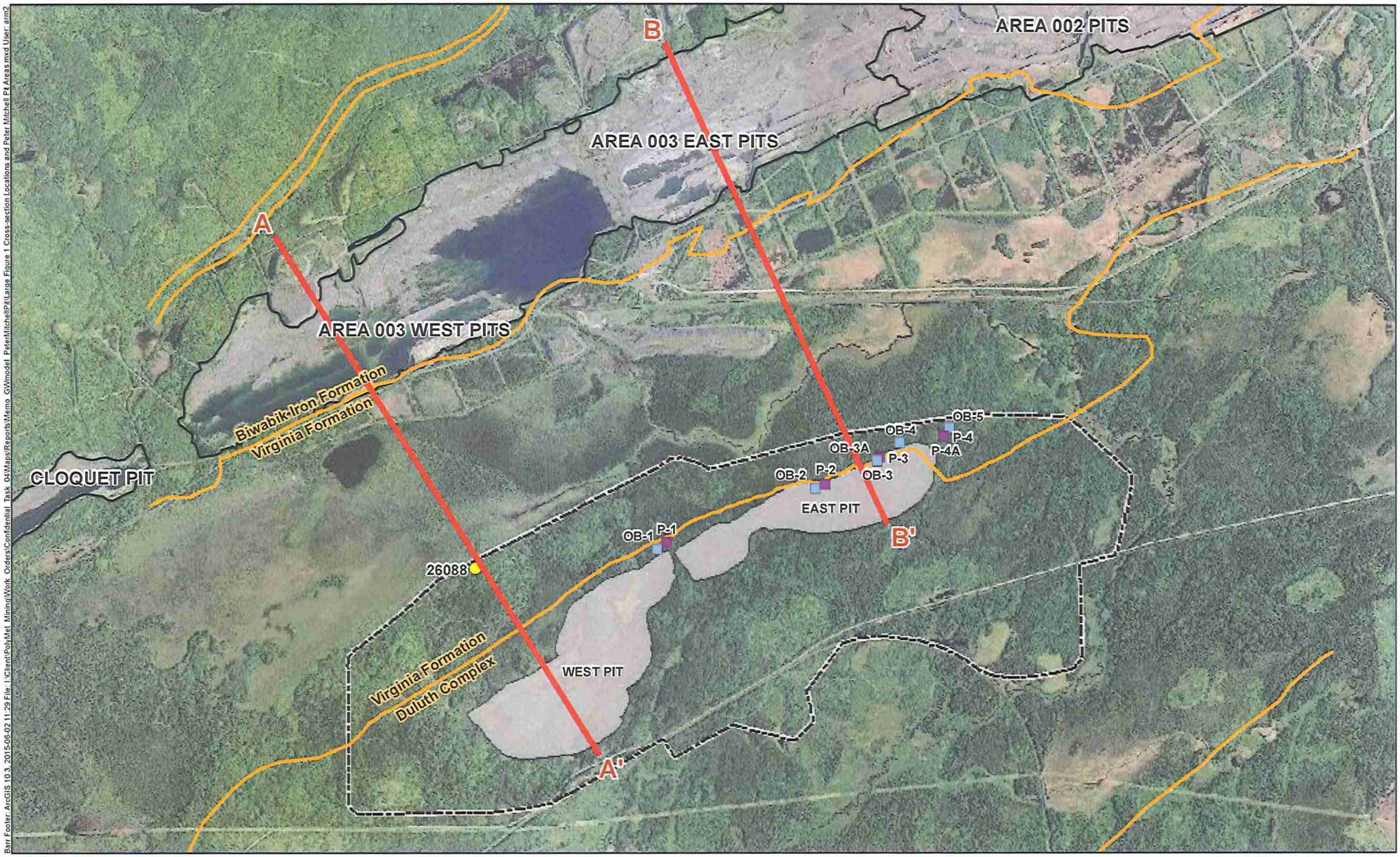
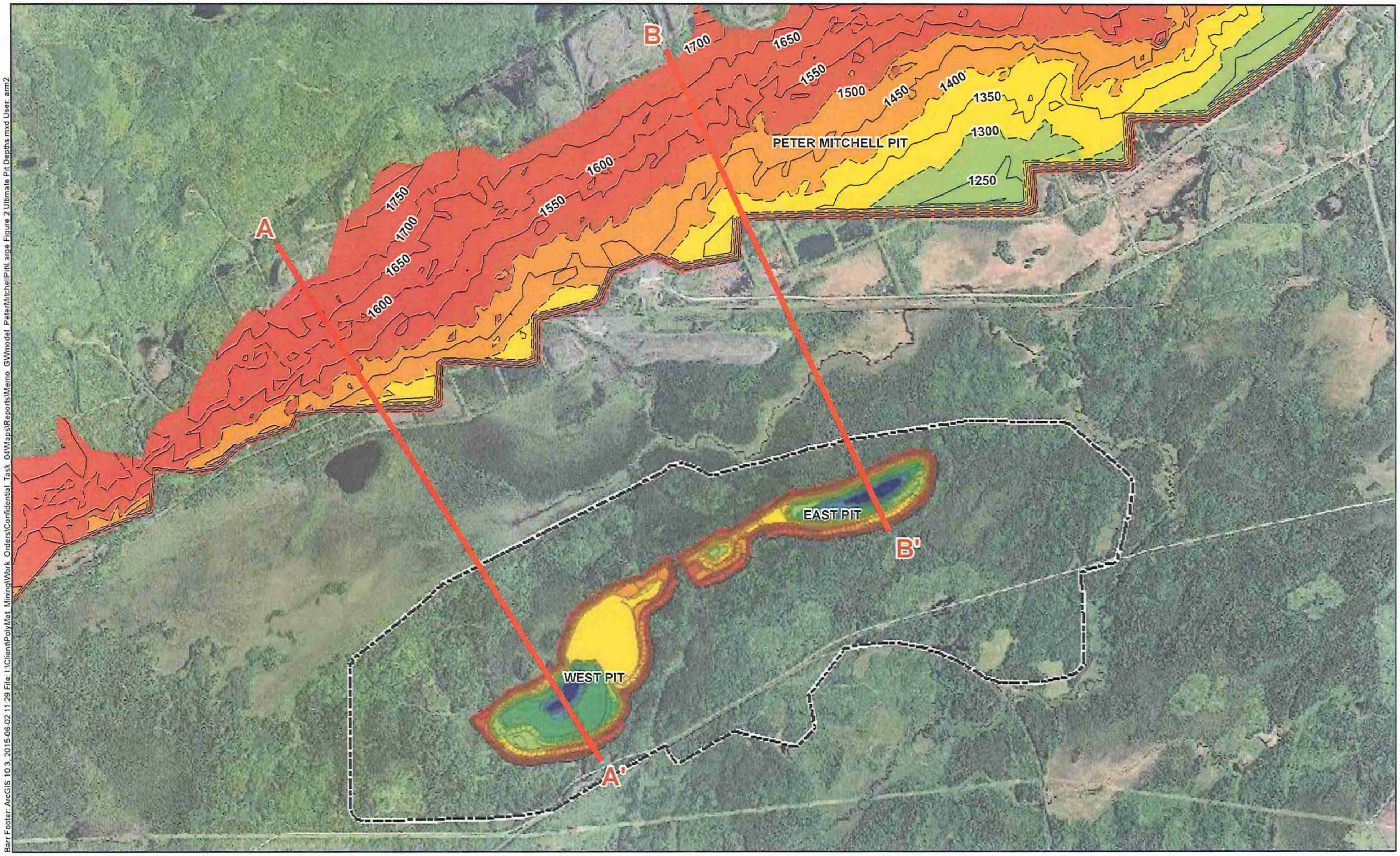


Drill Hole
Existing Bedrock Monitoring Wells
Observation Wells
Pumping Test Wells
Cross Section Locations
Geologic Contacts

Peter Mitchell Pit Areas
DNR Mining Features, 2013
NorthMet Mine Site
NorthMet Pits

0 1,750 3,500 7,000
Feet

Large Figure 1
CROSS SECTION LOCATIONS AND
PETER MITCHELL PIT AREAS
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, Minnesota



Cross Section Locations

NorthMet Mine Site

Future Topography (ft MSL)

920 - 1,000

1,000 - 1,100

1,100 - 1,200

1,200 - 1,300

1,300 - 1,400

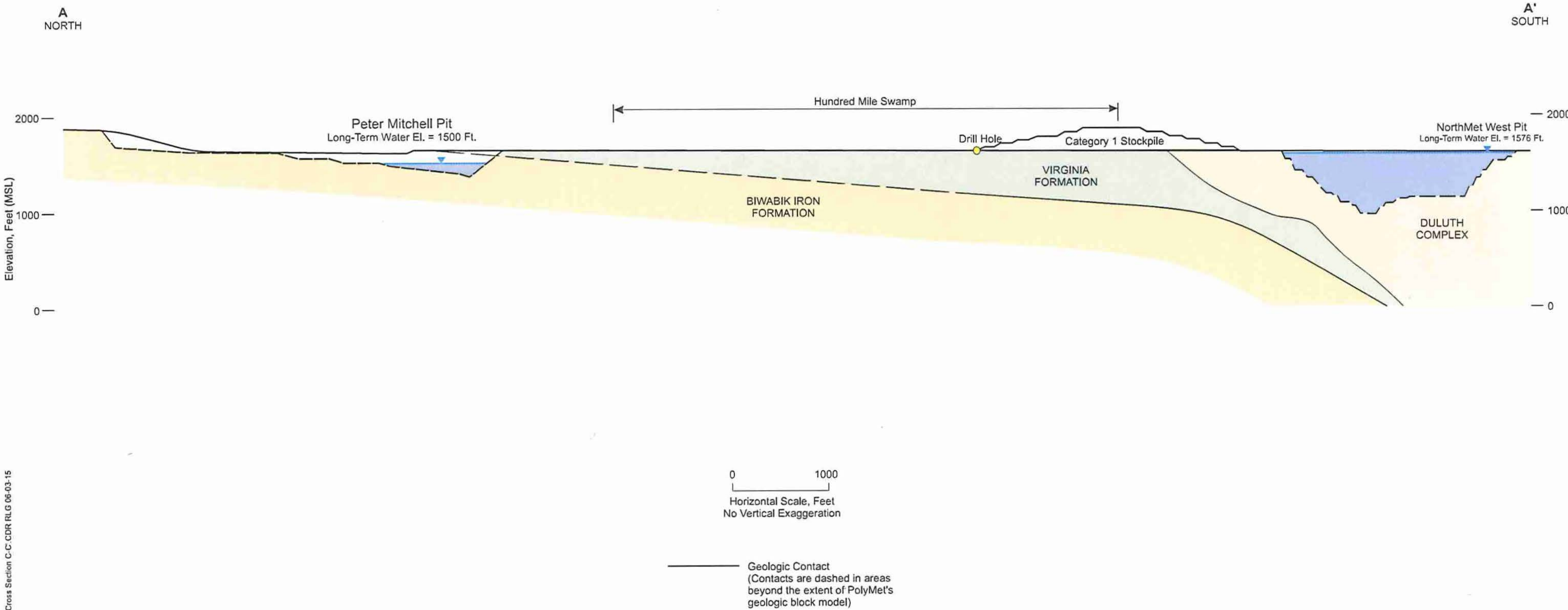
1,400 - 1,500

1,500 - 2,000

0 1,750 3,500 7,000

Feet

Large Figure 2
ULTIMATE PIT ELEVATIONS
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, Minnesota



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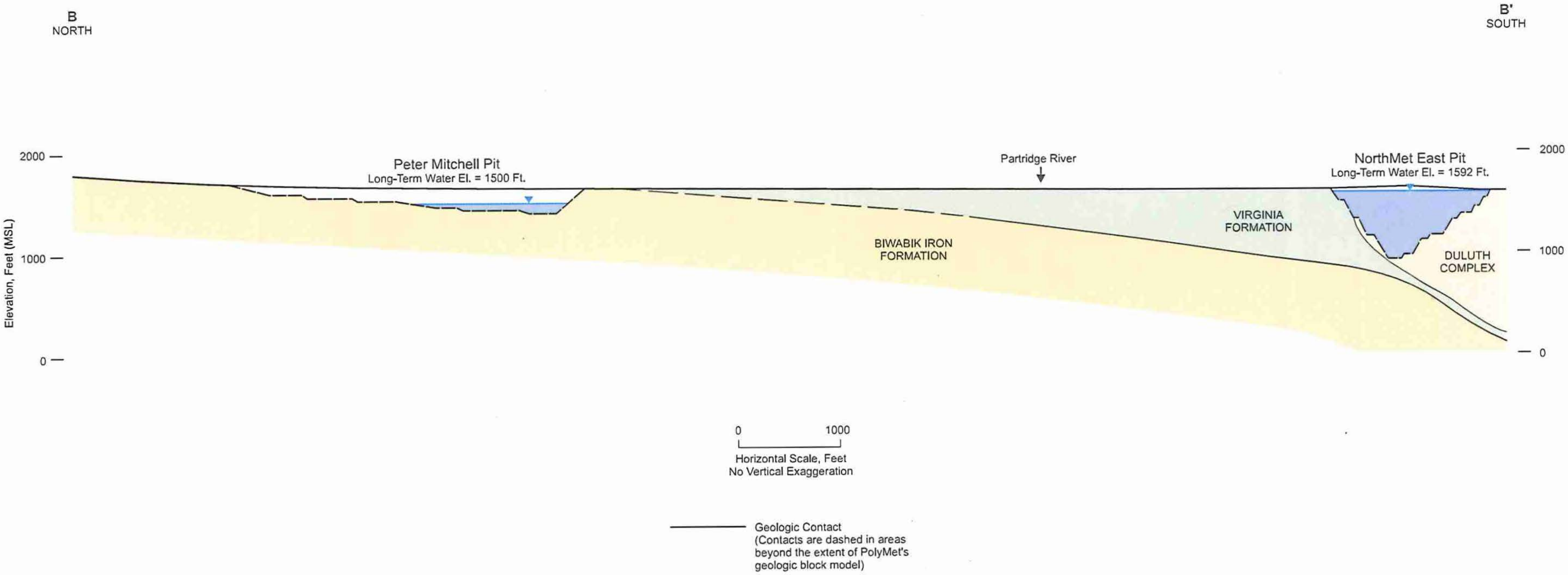
Large Figure 3

CROSS-SECTION A-A'
PolyMet Mining
Hoyt Lakes, MN



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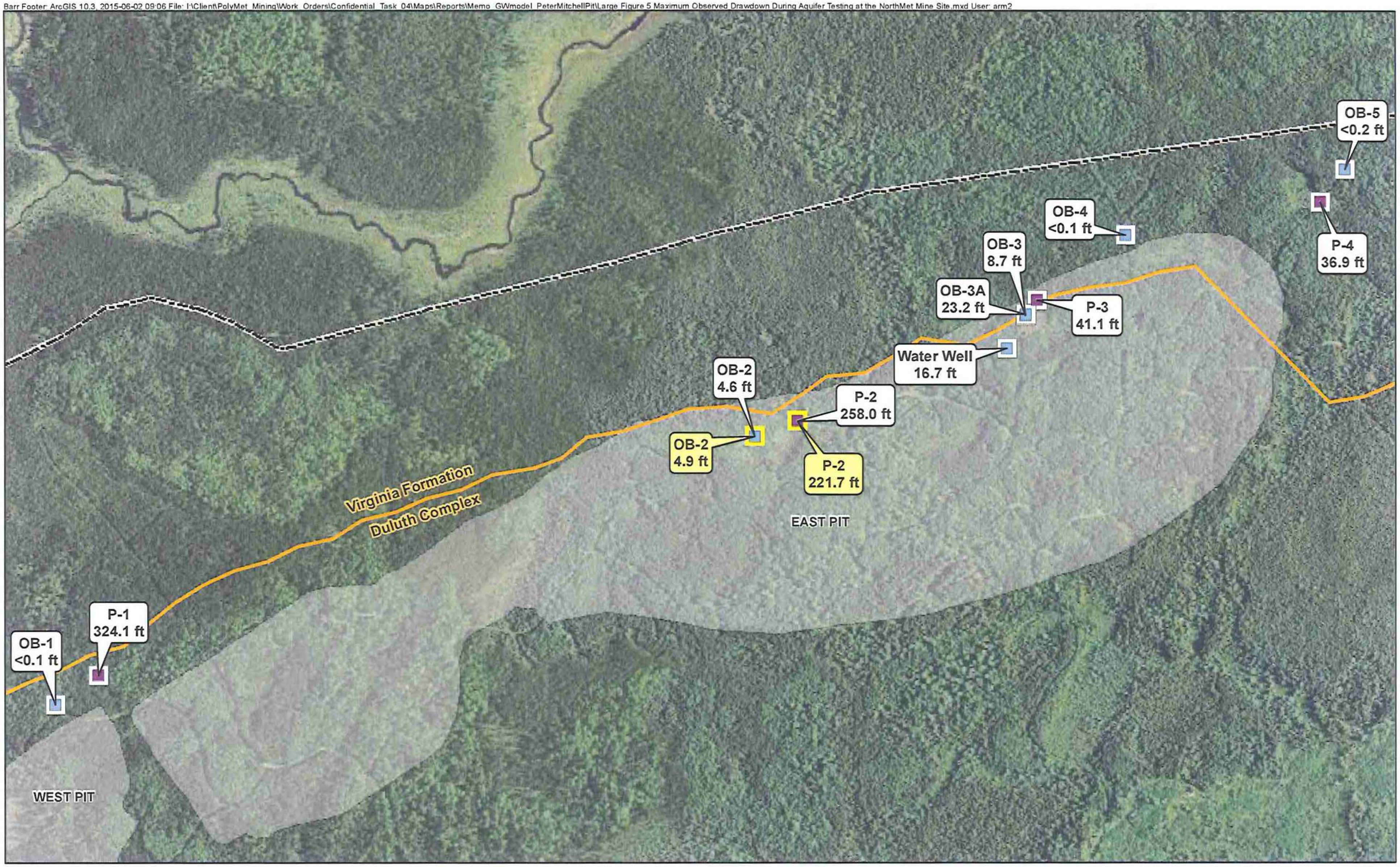
Large Figure 4

CROSS-SECTION B-B'
PolyMet Mining
Hoyt Lakes, MN

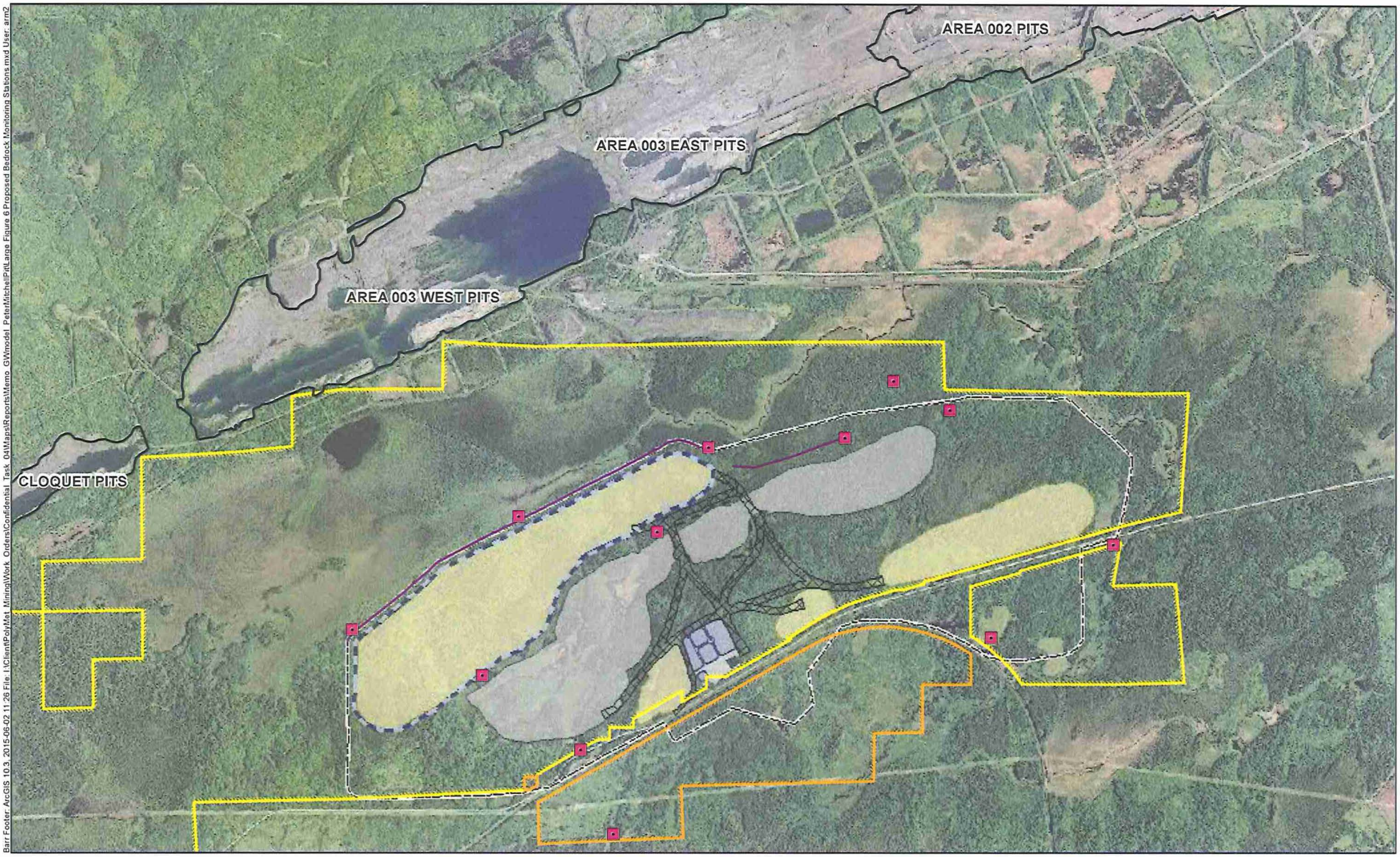


Existing Bedrock Monitoring Wells

- Observation Wells
- Pumping Wells
- Aquifer Test Phase II
- Aquifer Test Phase II and Phase III
- Geologic Contacts
- NorthMet Mine Site
- NorthMet Pits
- OB-1 <0.1 ft — Well Name, Phase II Maximum Drawdown
- OB-1 <0.1 ft — Well Name, Phase III Maximum Drawdown

0 400 800 1,600
Feet

Large Figure 5
MAXIMUM OBSERVED DRAWDOWN DURING AQUIFER TESTING AT THE NORTHMET MINE SITE
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, Minnesota



Proposed Bedrock Monitoring Wells
NorthMet Mine Site
Peter Mitchell Pit Areas
DNR Mining Features, 2013
PolyMet Owned/Leased Area
USFS Federal Land Exchange Parcel

Mine Layout - Year 11
Mine Pit
Active Stockpile
Removed Stockpile
Haul Roads
Groundwater Containment System
Perimeter Dike

0 1,750 3,500 7,000
Feet

Large Figure 6
PROPOSED BEDROCK MONITORING STATIONS
NorthMet Project
Poly Met Mining Inc.
Hoyt Lakes, Minnesota

ERRATA SHEET –ATTACHMENT 2
Final Environmental Impact Statement
PolyMet Mining, Inc. – NorthMet Mining Project and Land Exchange
November 24, 2015

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SHORT COMMUNICATION

A PRESUMPTIVE STANDARD FOR ENVIRONMENTAL FLOW PROTECTION

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ABSTRACT

The vast majority of the world's rivers are now being tapped for their water supplies, yet only a tiny fraction of these rivers are protected by any sort of environmental flow standard. While important advances have been made in reducing the cost and time required to determine the environmental flow needs of both individual rivers and types of rivers in specific geographies, it is highly unlikely that such approaches will be applied to all, or even most, rivers within the forseeable future. As a result, the vast majority of the planet's rivers remain vulnerable to exploitation without limits. Clearly, there is great need for adoption of a "presumptive standard" that can fill this gap. In this paper we present such a presumptive standard, based on the Sustainability Boundary Approach of Richter (2009) which involves restricting hydrologic alterations to within a percentage-based range around natural or historic flow variability. We also discuss water management implications in applying our standard. Our presumptive standard is intended for application only where detailed scientific assessments of environmental flow needs cannot be undertaken in the near term. Copyright © 2011 John Wiley & Sons, Ltd.

KEY WORDS: environmental flow; sustainability; Sustainable Boundary Approach; river management; corporate water use; water stewardship; water allocation; water scarcity

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Available freshwater supplies are being increasingly strained by growing human demands for water, particularly for irrigated agriculture and urban uses. The global population is growing by 80 million people each year, and if consumption patterns evolve as expected, two-thirds of the world's population will live in water-stressed areas by 2025 (WWAP, 2009). Whereas differing patterns of population growth, lifestyle changes and climate change will pose different scenarios on each continent, water managers and planners are challenged to meet growing water needs virtually everywhere.

At the same time, societies around the world are increasingly demanding that water managers also protect the natural freshwater ecosystems that are being tapped for water supplies. The need to protect 'environmental flows'—defined as the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems (Brisbane Declaration, 2007)—is now being addressed in many governmental water allocation policies, dam development plans and urban water supply plans. The stimuli for protecting environmental flows are varied and many, including the desire to protect biodiversity, ecosystem services (especially fisheries production), water-based tourism or recreation, economic activities such as hydropower generation and other cultural or spiritual values (Postel and Richter, 2003).

However, many good intentions to protect environmental flows have stalled upon encountering confusing and conflicting information about which method for environmental flow assessment is appropriate or 'best' and perceptions that the more credible and sophisticated methods require considerable investment of time, expertise and money to apply. These real and perceived hurdles have too often resulted in doing nothing to protect environmental flows, leaving the vast majority of rivers on the planet vulnerable to over-exploitation (Richter, 2009).

The environmental flow science community has long been attuned and responsive to the need for more cost-efficient and time-efficient approaches to determining environmental flow needs. Beginning in the 1970s with the Tennant (1976) method and continuing with the recent publication of the 'Ecological Limits of Hydrologic Alteration' (ELOHA; Poff *et al.*, 2010), a long series of efforts have been put forth by scientists to streamline and expedite environmental flow assessment while maintaining scientific credibility. However, widespread environmental flow protection across the planet's river networks has yet to be attained.

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Of particular concern and relevance to this paper is the fact that it is proving difficult to implement ELOHA in some jurisdictions even though the approach was explicitly designed to address the issues that have prevented other methods from being applied widely. The four co-authors of this paper have been actively encouraging government entities to apply the ELOHA framework; the difficulties we have experienced in these efforts have provided strong motivation for writing this paper. As we explain later in this paper, we continue to believe that ELOHA provides the best available balance between scientific rigor and cost of application for setting environmental flow standards for many rivers simultaneously. The ELOHA framework is currently being applied in various jurisdictions around the world. However, we are finding that many government entities are unable (or unwilling) to afford the cost of applying ELOHA (generally ranging from \$100k to \$2M), especially in situations where existing biological data and hydrologic models have poor spatial coverage. Time constraints are an even more frequent hindrance to the implementation of the ELOHA framework, particularly for jurisdictions embroiled in politically challenging situations such as responding to extreme droughts, legislative mandates or lawsuits. We suggest that until ELOHA or some variation can be applied everywhere, a presumptive, risk-based environmental flow standard is needed to provide interim protection for all rivers.

Another strong motivation for putting forth a presumptive standard at this time is the fact that many large water-using corporations are now looking for environmental indicators that can help them screen their operations and supply chains for water-related risks (e.g. SABMiller and WWF-UK, 2009). These corporations are increasingly coming to understand that, when environmental flows are not adequately protected, freshwater ecosystems will be stressed, jeopardizing ecosystem services valued by many people for their livelihoods and well-being. This can lead to conflicts that can ultimately endanger a company's 'social licence to operate' (Orr *et al.*, 2009). Presently, many corporations are using estimates for environmental flow requirements put forth by Smakhtin *et al.* (2004); these estimates range globally from 20% to 50% of the mean annual river flow in each basin. We agree with Arthington *et al.* (2006) that such a low level of protection as suggested by Smakhtin 'would almost certainly cause profound ecological degradation, based on current scientific knowledge'. We hope that the presumptive standard we offer in this paper will replace corporate use of the Smakhtin estimates for water risk screening.

The presumptive standard for environmental flow protection put forth in this paper is intended for use only in situations where the application of ELOHA or site-specific environmental flow determinations (e.g. Richter *et al.*, 2006) cannot be applied in the near future; in other words, it is intended for use as a default placeholder. This presumptive standard is derived from the sustainability boundary approach (SBA) described by Richter (2009), which involves maintaining flows within a certain percentage-based range around natural flows (i.e. flows in the absence of dam regulation or water withdrawals).

Before discussing our proposed presumptive standard in greater detail, we provide a short discussion of the advantages of 'per cent-of-flow' (POF) approaches such as the SBA for expressing environmental flow requirements. We then summarize efforts around the world to apply flow protection standards based on POF expressions. Finally, we propose a specific presumptive standard using risk bands placed around natural flow variability and conclude with management implications in applying this presumptive standard.

APPROACHES FOR SETTING FLOW PROTECTION STANDARDS

A primary challenge in setting flow protection standards is to employ a practical method that limits water withdrawals and dam operations in such a way as to protect essential flow variability. As described by Richter (2009), a large body of scientific literature supports the 'natural flow paradigm' as an important ecological objective to guide river management (Richter *et al.*, 1997; Poff *et al.*, 1997; Bunn and Arthington, 2002; Postel and Richter, 2003; Arthington *et al.*, 2006). Stated simply, the key premises of the natural flow paradigm are that maintaining some semblance of natural flow regimes is essential to sustaining the health of river ecosystems and that health is placed at increasing risk with increasing alteration of natural flows (Richter *et al.*, 2003; Richter, 2009).

Three basic approaches have been employed for setting environmental flow standards across broad geographies such as states or nations: minimum flow thresholds, statistically based standards and POF approaches. The most commonly applied approach to date has been to set a minimum flow level that must be maintained. For example, the most widely used minimum flow standard in the USA is the annual 7Q10, which is defined as the lowest flow for seven consecutive days that occurs every 10 years on average. Whereas the original intent of the annual 7Q10 flow standard was to protect water quality under the federal Clean Water Act of 1972, it has become either explicitly in rule or by default the minimum flow threshold in many states (Gillilan and Brown, 1997; IFC, 2001). The growing recognition that this threshold was not sufficiently protective of aquatic habitats led in the 1980s and 1990s to several states setting higher flow thresholds, such as by setting the minimum level at 30% of the mean annual flow (MAF) or by setting thresholds that vary seasonally, such as at the

DOI: 10.1002/rra

level of 60% of MAF in winter, 30% of MAF in summer and 40% of MAF in spring and fall (Gillilan and Brown, 1997; IFC, 2001).

More recently, statistically based standards have been used to maintain certain characteristics of the flow regime. For example, such a standard may call for protecting a high flow of a specified magnitude, with specified duration, to occur with a specified inter-annual frequency. The application of a statistically based standard in regulating water use generally involves using computerized hydrologic models to simulate the cumulative effects of licenced or proposed water withdrawals and dam operations on the flow regime; hydrologic changes are allowed to accumulate until the statistical standards would be violated by further withdrawals or dam effects.

Flow standards set in the USA, the European Union and elsewhere in the past decade have increasingly been based on a POF approach (see case studies later in this paper). This approach explicitly recognizes the importance of natural flow variability and sets protection standards by using allowable departures from natural conditions, expressed as percentage alteration. The POF approach has several strong advantages over other approaches. For instance, the POF approach is considerably more protective of flow variability than the minimum threshold standards. Minimum-threshold-based standards can allow flow variability to become 'flat-lined' as water allocation pressure increases and reservoir operations are designed only to meet minimum release requirements. Statistically based standards, although usually more protective of flow regimes than minimum thresholds, can be confusing to non-technical stakeholders, and complex statistical targets have proven difficult for water managers to implement (Richter, 2009). By comparison, POF approaches are conceptually simple, can provide a very high degree of protection for natural flow variability and can also be relatively simple to implement (i.e. a dam operator simply releases the prescribed percentage of inflow, or cumulative water withdrawals must not reduce flow by more than the prescribed percentage).

Sustainability boundary approach

Recognizing that human-induced flow alterations can both deplete and unnaturally augment natural flows to the detriment of ecological health, Richter (2009) expanded upon the POF approach by suggesting that bands of allowable alteration called 'sustainability boundaries' could be placed around natural flow conditions as a means of expressing environmental flow needs, as depicted in Figure 1.

To apply the SBA, the natural flow conditions for any point of interest along a river are estimated on a daily basis, representing the flows that would have existed in the absence of reservoir regulation, water withdrawals and return flows (Richter, 2009). Limits of flow alteration, referred to as sustainability boundaries, are then set on the basis of allowable perturbations from the natural condition, expressed as percentage-based deviations from natural flows. Those withdrawing water or operating dams are then required to maintain downstream river flows within sustainability boundaries. Whereas maintaining flows within the targeted range may be infeasible on a real-time basis in many cases, such management can be facilitated by creating computerized hydrologic models to evaluate what the likely perturbation to natural flows would be under existing or proposed scenarios of water withdrawal and dam operations and by licencing such water uses accordingly.

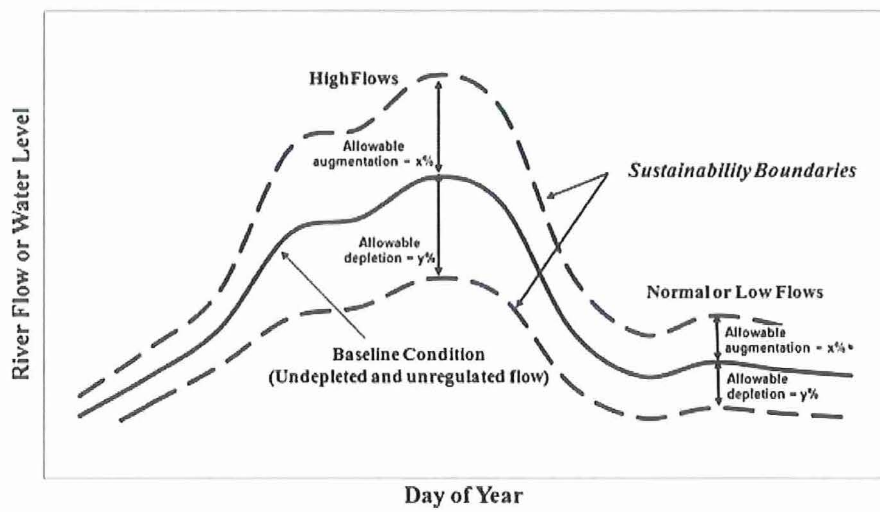

Figure 1. Illustration of the sustainability boundary approach from Richter (2009; reprinted with permission). The sustainability boundaries set limits on the degree to which natural flows can be altered, expressed as a percentage of natural flows.

DOI: 10.1002/rra

The allowable degree of alteration from the natural condition can differ from one point to another along the same river. This determination for any point of interest along a river requires a negotiation or optimization between the following: (i) the desired consumption or dam regulation of water upstream, which might either deplete or unnaturally augment river flows; (ii) the desired uses of water downstream; and (iii) the desired ecological condition and ecosystem services to be maintained. As such, the SBA forces an explicit integration of environmental flow objectives with water withdrawals and dam operations. We recognize and emphasize that this is a socio-political decision-making process as much as it is a scientific one. As suggested by Richter (2009), the application of the SBA in setting river flow management goals requires transparent, inclusive and well-informed stakeholder engagement.

The basic challenge confronting environmental flow proponents is the difficulty of determining how much alteration from natural flows can be tolerated without compromising ecological health and ecosystem services to an undesirable degree. In the absence of such an understanding, water managers and governmental regulators have focused solely on water withdrawals and dam operations, providing only minimum flow protection or neglecting ecosystem considerations altogether. This highly undesirable situation calls for the adoption of a precautionary approach to fill the gap, until more detailed and regionally tailored studies of environmental flow needs can be completed and used to set flow protection standards.

We believe that sufficient scientific evidence and knowledge now exist to propose an SBA-based presumptive standard that can serve as initial guidance for regulating water withdrawals and dam operations in rivers. In designing the presumptive standard recommended later in this paper, we reviewed numerous other efforts to set environmental flow standards that apply across broad regions and many different rivers.

CASE STUDY REVIEW

The following case studies represent environmental flow policies and management guidelines that are being applied in the USA and Europe to limit flow alteration and to achieve relatively high levels of ecological protection, while allowing for carefully managed water development to proceed. Whereas not all of these cases can be characterized as pure POF approaches, we believe that these case studies illustrate useful and progressive water management policies that fulfill the intent of the SBA. They are described here to demonstrate the feasibility of applying standards in a manner consistent with the SBA and to support our recommendations for the presumptive standard described later in this paper.

Example #1—Southwest Florida Water Management District

Under the Florida state law, the state's five water management districts must determine 'minimum flows and levels' (MFLs) for priority water bodies of the state. Methods to determine MFLs differ among the five districts. The Southwest Florida Water Management District (SWFWMD) uses a POF-based approach that includes use of multiple environmental flow assessment methods, including the Instream Flow Incremental Methodology and the Wetted Perimeter approach (see IFC, 2001 for descriptions of these methods), to inform the setting of percentage alteration limits. The intent of the resulting MFLs is to limit water withdrawals such that physical habitat losses do not exceed 15% (Flannery *et al.*, 2002, 2008). The allowable flow reduction, which is referenced to as previous-day flows at a specified river gauge, can vary with season and with magnitude of flow and includes a 'hands-off' low flow threshold, meaning that all withdrawals are curtailed once the flow threshold is reached (see Rules of the Southwest Florida Water Management District, Chapter 40D-8, Water Levels and Rates of Flow, Section 40D-8.041 Minimum Flows at www.swfwmd.state.fl.us).

These MFLs are used in water management planning and incorporated as water withdrawal permit conditions. The percentage of allowable depletion has been set by SWFWMD for five non-tidal rivers in the district, ranging from 8% to 15% during high flows and 10% to 19% during low flows. Allowable depletions tend to be larger for freshwater flows into estuaries. For example, the lower Alafia River can be depleted up to 19% as it enters its estuary, based on limiting fish habitat loss caused by changes in salinity and dissolved oxygen to no more than 15%. No withdrawals are allowed when flows fall below 120 ft^3/s, based on chlorophyll residence time in the estuary, fish, dissolved oxygen and comb jellyfish. The proposed MFL for the Lower Peace River and its estuary limits withdrawals to flows above 130 ft^3/s, with allowable 16% reduction of daily flow up to a flow rate of 625 ft^3/s, 29% flow reductions in fall/winter and 38% flow reductions in summer above 625 ft^3/s (Flannery *et al.*, 2002, 2008).

Example #2—Michigan's Water Withdrawal Assessment Tool Approach

The Great Lakes–St Lawrence River Water Resources Compact and related state law require limits on water withdrawals to prevent 'adverse resource impact', defined as the point when 'a stream's ability to support characteristic fish populations is functionally impaired'. Zorn *et al.* (2008) documented the work of the Michigan Department of Natural Resources to develop a predictive model of how

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fish assemblages in different types of Michigan streams would change in response to decreased summer base flows, using habitat suitability information for over 40 Michigan fish species. The approach involved classification of all river segments in the state based on size and temperature regime and the development of a fish response curve that relates assemblage richness to an index flow (median August streamflow) for each of the 11 river classes. This index flow serves as a surrogate for withdrawals as a POF.

Across the majority of river types in Michigan, 'baseline or existing' ecological conditions are predicted to be maintained with cumulative withdrawals less than 6–15% of the index flow, depending on the stream type (Seelbach *et al.*, 2009). This is roughly equivalent to maintaining excellent ecological condition for many rivers, but some rivers that have historically been degraded would only be maintained in their current condition (Paul Seelbach, personal communication, University of Michigan, Ann Arbor). Adverse resource impacts are predicted to occur on most types of rivers with withdrawals greater than 17–25% of index flow. Rivers classified as 'transitional' between cold and cool rivers are very sensitive to withdrawals and are limited to withdrawals of 2–4% index flows before adverse resource impact is predicted to occur.

The Michigan Water Withdrawal Assessment Tool (WWAT) allows estimation of the likely impact of a water withdrawal on nearby streams and rivers using these threshold values. Use of the WWAT is required of anyone proposing to make a (large) new or increased withdrawal from the waters of the state, including all groundwater and surface water sources, prior to beginning the withdrawal. The WWAT is online at http://www.miwwat.org/.

Unlike Florida's POF approach, which references allowable depletions to a percentage of the previous day's flow, the Michigan approach references its withdrawal limits only to the August median flow. Because August is typically the lowest flow month in Michigan and Michigan flow regimes are fairly predictable, it is unlikely that cumulative withdrawals beyond the adverse resource impact level would frequently exceed the percentage guideline in other months. However, in very dry summers, one would expect the adverse resource impact percentage to be exceeded for a portion of the summer.

Example #3—UK Application of the European Union Water Framework Directive

The European Union (EU) Water Framework Directive, passed in 2000, was designed to protect and restore aquatic ecosystems by setting common ecological objectives across EU member states. The Water Framework Directive requires member states to achieve a 'Good Ecological Status' in all surface waters and groundwaters that are not determined to already be 'heavily modified'(Acreman *et al.*, 2006). It is assumed that meeting the Good Ecological Status requires protecting or restoring ecologically appropriate hydrological regimes, but the Water Framework Directive itself does not define environmental flow standards for any country in the EU (Acreman and Ferguson, 2010).

In the UK, a Technical Advisory Group worked with conservation agencies and academics to begin defining environmental standards for physio-chemical and hydromorphological conditions necessary to meet different levels of ecological status (Acreman *et al.*, 2006). A key part of this work was defining thresholds of allowable water withdrawal as a percentage of natural flow. To achieve this, a literature review was prepared, and numerous expert workshops were convened. Each river in the UK was assigned to one of 10 classes, based on physical watershed characteristics, to facilitate application of withdrawal thresholds (Acreman and Ferguson, 2010).

Withdrawal standards were based on professional knowledge and discussion of the flow needs of various plant and animal communities—primarily macrophytes, macroinvertebrates and fish. Quantitative standards for achieving Good Ecological Status were specified for four groupings of river types, two seasons and four tiers of withdrawal standards based on annual flow characteristics (Table I). The allowable abstraction values in Table I are intended to be restrictions on cumulative withdrawals, applicable to any point on a river of that type.

The withdrawal standards in Table I were derived from an expert consensus workshop approach by using the precautionary principle to deal with considerable uncertainty. Different tolerances to flow alteration were recognized across taxa groups, but a 10% flow alteration was generally seen by experts as likely to have negligible impact for most taxa, stream types and hydrologic conditions (Acreman and Ferguson, 2010). The workgroup also generally agreed upon a Q95 (i.e. fifth percentile) flow as being 'hands-off', meaning that at that flow withdrawal would either stop or be significantly reduced. The recommended allowable withdrawal levels increase with magnitude of flow and in cooler months. Thus, permissible alterations range from 7.5% to 20% in warm months at lower flows (below Q70) and from 20% to 35% during cooler months at higher flows (Acreman *et al.*, 2006).

Example #4—Maine sustainable water use rule

In 2001, the Maine State Legislature passed a law requiring 'water use standards for maintaining instream flows…lake or pond water levels…protective of aquatic life and other uses…based on the natural variation of flows'. The resulting environmental flow and water level protection rule, finalized in 2007, establishes a set of tiered flow protection criteria

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Table I. Standards for UK river types/subtypes for achieving Good Ecological Status, given as per cent allowable abstraction of natural flow (thresholds are for annual flow statistics)

Type or subtype	Season	Flow >Q60	Flow >Q70	Flow >Q95	Flow <Q95
A1	Apr–Oct	30	25	20	15
	Nov–Mar	35	30	25	20
A2 (downstream), B1, B2, C1, D1	Apr–Oct	25	20	15	10
	Nov–Mar	30	25	20	15
A2 (headwaters)	Apr–Oct	20	15	10	7.5
C2, D2	Nov–Mar	25	20	15	10
Salmonid spawning and nursery areas	Jun–Sep	25	20	15	10
	Oct–May	20	15	Flow >Q80	Flow <Q80

From Acreman and Ferguson (2010).

linked to different stream condition classes (Maine DEP, 2010a). The environmental flow standards may be established by one of two methods: a standard allowable alteration of flow or a site-specific flow assessment. The standard allowable alteration is based on the natural flow regime theory (Poff *et al.*, 1997; Richter *et al.*, 1997) and was informed by considerable scientific research on environmental flow requirements for the eastern USA (e.g. Freeman and Marcinek, 2006).

For all streams falling into the state's best-condition class (class AA), 90% of the total natural flow must be maintained when the flow exceeds the spring or early winter 'aquatic base flow' (Maine DEP, 2010b). This aquatic base flow is defined as the median monthly flow of the central month of each season (Maine DEP, 2006). In other seasons, withdrawals of up to 10% of daily flow can only occur when daily flows exceed 1.1 to 1.5 times the seasonal aquatic baseflow. No flow alteration is allowed in any season when flows are below aquatic base flow levels. In addition, all rivers and streams that flow into class AA waters must meet the POF standard.

Although used only for those waters with the highest ecological condition goals, which make up approximately 6% of state waters, the Maine standard provides a good example of use of a hands-off flow level combined with a POF approach.

Summary of case study findings

The case studies summarized here have much in common (Table II). In each case, standards were developed with a general intent to avoid ecological degradation of riverine ecosystems. The specifics of management goals vary from case study to case study, but common among them is the desire to maintain ecological conditions that are good to excellent or to avoid ecological harm. Each of these efforts to set standards has utilized the best available science for their region, and each has engaged large numbers of scientists familiar with flow–ecology science, using expert-based decision-making processes.

We found the recommendations for flow protection emerging from these expert groups to be quite consistent, typically resulting in a range of allowable cumulative

Table II. Summary of per cent-of-flow environmental flow standards from case studies

Location	Ecological goal	Cumulative allowable depletion	Considerations	Decision process
Florida (SWFWMD)	Avoid significant ecological harm (max. 15% habitat loss)	8–19% of daily flow	Seasonally variable extraction limit; 'hands-off' flow	Scientific peer review of site-specific studies
Michigan	Maintain baseline or existing condition	6–15% of August median flow	Single extraction limit for all flow levels	Stakeholders with scientific support
Maine	Protect class AA: 'outstanding natural resources'	10% of daily flow	Single extraction limit for all flow levels above a 'hands-off' flow level	Expert derived
European Union	Maintain good ecological condition	7.5–20% of daily flow	Lower flow; warmer months; 'hands-off' flow	Expert derived
		20–35% of daily flow	Higher flow; cooler months	

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depletion of 6% to 20% of normal to low flows, but with occasional allowance for greater depletion in seasons or flow levels during which aquatic species are thought to be less sensitive (Table II). These results suggest a consensus that modest alteration of water flows can be allowed with minimal to no harm to aquatic ecosystems and species.

A PROPOSED PRESUMPTIVE STANDARD

Our review of the case studies described above suggests that an appropriate presumptive standard for environmental flow protection can be proposed at this time, subject to some important caveats.

We suggest that a high level of ecological protection will be provided when daily flow alterations are no greater than 10%; a high level of protection means that the natural structure and function of the riverine ecosystem will be maintained with minimal changes. A moderate level of protection is provided when flows are altered by 11–20%; a moderate level of protection means that there may be measurable changes in structure and minimal changes in ecosystem functions. Alterations greater than 20% will likely result in moderate to major changes in natural structure and ecosystem functions, with greater risk associated with greater levels of alteration in daily flows. These thresholds are well supported by our case study review, as well as from our experiences in conducting environmental flow assessments for individual rivers (e.g. Richter *et al.*, 2003, 2006; Esselman and Opperman, 2010). This level of protection is also generally consistent with findings from regional analyses such as the 'benchmarking' study in Queensland, Australia, by Brizga *et al.* (2002) and by a national (US) analysis of hydrologic alteration which documented that biological impairment was observed in some sites with hydrologic alteration of 0–25% (the lowest class of alteration assessed) and in an increasing percentage of sites beyond 25% hydrologic alteration (Carlisle *et al.*, 2010).

This presumptive standard can be represented graphically as shown in Figure 2, using the convention of the SBA (Richter, 2009), with risk bands bracketing the daily natural flow conditions. When a single threshold value or standard is needed, such as for corporate risk screening or water supply planning purposes, we suggest that protecting 80% of daily flows will maintain ecological integrity in most rivers. A higher percentage of flow (90%) may be needed to protect rivers with at-risk species and exceptional biodiversity.

Whereas we believe that such a presumptive standard of limiting daily flow alterations to 20% or less is conservative and precautionary, we also caution that it may be insufficient to fully protect ecological values in certain types of rivers, particularly smaller or intermittent streams. Seasonal adjustments of the per cent of allowable depletion may be advisable. Several of our case studies utilized 'hands-off' flow thresholds to limit impacts to the frequency and duration of low-flow events. This may be an additional consideration where fish passage, water quality or other conditions are impaired by low flows. Also, when applying this presumptive standard to rivers affected by hydropower dams, imposing our suggested limits on daily flow averages may be insufficient to protect ecological integrity because of the propensity for peaking power operations to cause river flows to fluctuate considerably within each day. In such cases, our presumptive standard may need to be applied on an hourly, rather than daily, basis. Adjustments to our suggested values

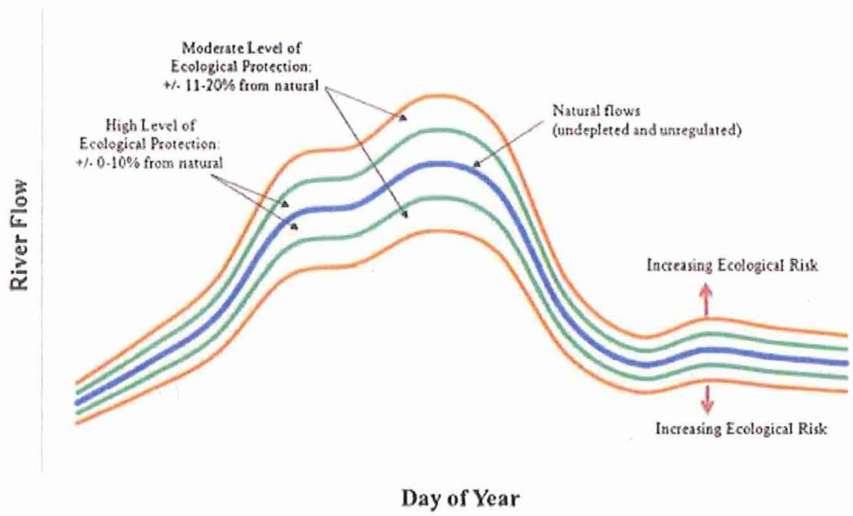

Figure 2. Presumptive standards are suggested for providing moderate to high levels of ecological protection. The greater the departure from natural flow conditions, the greater is the ecological risk to be expected. This figure is available in colour online at wileyonlinelibrary.com/journal/rra.

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should be considered when local or regional ecological knowledge indicates that narrower bands of allowable alteration are needed.

Most importantly, continued investment in detailed, site-specific or regional environmental flow assessment is urgently needed. Such research must continue to inform our understanding of flow–ecology relations and refine our presumptions about the adequacy of protecting different percentages of natural flows.

MANAGEMENT IMPLICATIONS

To properly apply our presumptive standard, water managers and other water stakeholders, such as corporations concerned about the sustainability of water use in particular river basins, will need to be able to do three basic things:

- Develop modelling tool(s) to estimate natural (unregulated and undepleted) flows on a daily basis; this provides the natural or 'baseline' flow data illustrated in Figure 1;
- Use the modelling tool(s) to evaluate whether *proposed* withdrawals, dam operations or other changes—when added to already-existing water uses—would cause the presumptive standard to be violated;
- Monitor daily flows at key locations, such as upstream and downstream of major water withdrawals and return flows, and at points of inflow to reservoirs, as a means for verifying and refining the modelling results and for regulatory enforcement purposes.

The capability to evaluate proposed hydrologic changes (second bullet in the above list) enables water managers to avoid issuing water use permits that would cause hydrologic variations to deviate outside of the sustainability boundaries set by the presumptive standard (±20%). Obviously, if a particular river's flow regime has already been altered more than ±20% during part or all of the time, water managers and stakeholders would need to decide whether to restore flows to a level consistent with the presumptive standard or adopt some other standard.

Application in over-allocated basins

Ongoing efforts to develop sustainable approaches to water management in the Murray-Darling river basin in Australia offer a highly relevant and useful example of re-balancing environmental and economic goals in a previously over-allocated basin. In response to considerable ecological degradation, heavy competition among water users, prolonged drought and climate change projections, the Commonwealth Parliament in 2007 passed a national water act calling for the development of a basin plan that would provide for integrated and sustainable management of water resources (MDBA, 2009). The Basin Plan is required to set enforceable limits on the quantities of surface water and groundwater that can be taken from the basin's water resources. These limits must be set at a level that the Murray-Darling Basin Authority, using the best available scientific knowledge, determines to be environmentally sustainable. This is defined as the level at which water in the basin can be taken from a water source without compromising the key environmental assets, the key ecosystem functions, the productive base or the key environmental outcomes of the water source. Considerable scientific analysis is being undertaken to determine environmental water requirements that will inform the determination of 'sustainable diversion limits'. Recent appropriations of federal funding to enable the buyback of historical entitlements can be used to reduce water usage to levels compatible with these diversion limits (Garrick *et al.*, 2009). The scientific assessment and decision-making being undertaken in the Murray-Darling basin exemplifies a situation in which our presumptive standard would have been violated by past water allocations, yet water managers and stakeholders are now striving to restore a level of ecological health and water use sustainability similar to the goals of our presumptive standard.

Technology requirements

The technology and capacity to manage water in this manner exist in many parts of the world, but we acknowledge that many water management institutions and corporations have not yet developed hydrologic modelling tools with the required level of temporal resolution (i.e. daily) to implement our presumptive standard. Similarly, few countries have been able to install and maintain daily flow monitoring networks with adequate spatial distribution to facilitate data collection and regulation of water uses in the manner we suggest. However, recent and ongoing advances in modelling approaches and technologies, as well as improvements in flow monitoring instrumentation, are driving down the expense of implementing this type of water monitoring and modelling programme. Given growing water scarcity and its economic implications, investment in this level of water management capacity should be given high priority by governments at all levels.

We recognize that many water planners continue to use hydrologic models that operate on a monthly time step. We can offer some guidance and caution. Although it is consistent with our presumptive standard to assume for planning purposes that 20% of the natural monthly mean flow can be allocated for consumptive use, this does not mean that a volume of water equivalent to 20% of the monthly mean can be allocated on a fixed basis without violating our presumptive standard. We illustrate this point

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with a simple hypothetical example. Let us say that the mean monthly flow in July is 100 m^3/s. You allocate a sum total of 20 m^3/s (20% of mean) for that month. Our presumptive standard will be violated each day in July that natural daily flows (recorded upstream or modeled) drop below100 m^3/s, which will be the case during the majority of the time for most river types. Therefore, the only way to be assured that our presumptive standard will not be violated given a monthly allocation will be to subsequently model the system at a daily time step to check for compatibility with the standard under the range of flows typically experienced by the river. Once such compatibility is assured, the water authority can confidently grant water use permits based on fixed amounts (i.e. monthly allocations or continuous rates of use) that provide the water user with desirable certainty.

Utility for water planning

Although implementation of our presumptive standard will require considerable investment in adequate technology and expertise as outlined previously in this paper, we want to emphasize that our presumptive standard will also be quite useful for initial water planning purposes that require less technological investment. As discussed in our introduction, many large corporations have become quite concerned about their water-related business risk and are interested in approaches that can help them screen for such risk across many facilities and parts of their supply chains. We suggest that our presumptive standard will be highly appropriate in risk screening, wherein estimates of water availability and use are available for river basins of interest. Our presumptive standard can be used to identify river basins in which water flows appear to have been altered by more than 20%, thereby posing considerable potential risk. In this sense, we are pleased to see the incorporation of a variation of our presumptive standard in the *Water Footprint Assessment Manual* (Hoekstra *et al.*, 2011), which is already being used by many corporations.

Implications for water supply and storage

We recognize that in most hydrologic settings, storage will be required to enable full utilization of up to 20% of the available daily flow for consumptive use. Creating such storage can lead to ecological impacts (such as impediments to fish migrations or blocking sediment transport) that can undo the ecological benefits that our presumptive flow standard is trying to protect. Therefore, we strongly urge water managers and engineers to employ innovative options for water storage—such as off-stream reservoirs or groundwater storage—that do not involve on-stream reservoirs. Alternatively, in systems in which storage reservoirs already exist, enlarging the capacity of those existing facilities will in most cases be far preferable to building new reservoirs.

Some water managers will feel excessively constrained by having to operate within the constraints of the presumptive sustainability boundaries suggested here. However, managing water sustainably necessarily implies living within limits (Richter *et al.*, 2003; Postel and Richter, 2003; Richter, 2009). We suggest that a strong social imperative has emerged that calls for setting those limits at a level that avoids damaging natural systems and the benefits they provide, at least as a default presumption. Where other socio-economic priorities suggest the need for relaxation of the presumptive sustainability boundaries we suggest here, we strongly encourage governments and local communities to invest in thorough assessments of flow–ecology relationships (Richter *et al.*, 2006; Poff *et al.*, 2010), so that decision-making can be informed with scientific assessment of the ecological values that would likely be compromised when lesser degrees of flow protection are adopted.

In our experiences in working with water and dam managers, we have found that a remarkable degree of creativity and innovation emerges when engineers and planners are challenged to meet targeted or forecasted water demands with the least disruption to natural flow patterns. Solving the water equation will require new thinking about how and where to store water, conjunctive use of surface water and groundwater, sizing diversion structures or pumps to enable extraction of more water when more is available during high flows, sizing hydropower turbines such that maximum power can be generated across a fuller range of flows, and other innovations. When such creativity is applied as widespread common practice, human impacts on freshwater ecosystems will most certainly be reduced substantially.

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