Assessment of Climate Variability on Water Resource Availability for Oil Shale Development

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Abstract

Commercial prospects for oil shale development are under consideration in the Piceance Basin in Northwest Colorado. The hydrocarbon-rich Piceance Basin lies in a region with limited precipitation, where rivers must sustain water demands from municipal, industrial, and agricultural activities in addition to baseline environmental flows. Water resource competition would be intensified with the introduction of oil shale operations, which require between 1 and 3 barrels of water per barrel of oil produced. This project analyzes the impact of climate variability on water availability for oil shale development in the Piceance Basin. Surface water data from the White River was used to perform water availability analyses: (1) a threshold-based low flow analysis to determine the frequency and duration of river flows that fall below flows of interest for instream habitat and operations, and (2) a reservoir size analysis to determine the capacity required to support uninterrupted oil shale operations while maintaining instream flows. Findings demonstrate a need for new off river reservoirs to ensure environmental flows during periods of drought. The analyses showed that a storage volume of 6,500 acre-ft is needed to sustain production of 250,000 barrels of oil per day. A storage volume of 15,500 acre-ft is needed to sustain production of 500,000 barrels of oil per day. Watershed analyses are underway to develop resource management strategies to minimize risks to oil shale operations while protecting instream flows and other water needs.

Introduction

The Green River Formation in the Western U.S. contains the largest oil shale deposits in the world **(Figure 1)**. Colorado's Piceance Basin alone contains approximately 500 billion barrels of recoverable shale oil, equivalent to half the world's proven oil reserves. It is conceivable that this region could eventually produce a quarter of the US daily demand, or up to 5 million barrels per day (Mmbbl/d). With the development of oil shale in the Piceance Basin, the Colorado River and its tributaries would become an important source of water for operations. This project aims to understand the impact of oil shale development on basin water resources, and in particular, the White River, by answering the following three questions:

How much fresh water will be required for commercial oil shale development?

How does climate variability affect surface water availability in the basin?

Can we manage surface water resources in the Piceance basin to accommodate oil shale development while protecting other water uses?

Source: Oil and Gas Journal, http://www.fe.doe.gov/programs/reserves/publications/Pubs-NPR/40010-373.pdf

Figure 1. Location of the Green River Formation Oil Shale Deposits, the Piceance Basin and the White River.

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How Much Water Will Oil Shale Need?

The Rand Report[1] projects that the oil shale industry will reach a production rate of 2.5 Mmbbl/d by the year 2035. This industry will need water for mining and handling, refining, retorting, cooling, dust control and reclamation. Water requirements for such activities vary widely according to the resource location and the technology utilized. Current estimates based on updated oil shale industry water budgets suggest that water requirements for new retorting methods will be between 1 and 3 barrels of water per barrel of oil. For an oil shale industry producing 2.5 Mmbbl/d, this equates to between 105 and 315 million gallons of water per day (MGD). These numbers include water requirements associated with power generation for in-situ heating processes, and other processes listed above, but do not include municipal and other water requirements related to population growth associated with industry development.

The 1980 OTA[2] report assessed that a 1.0 Mmbbl/d industry would attract between 118,000 and 236,000 new residents to the area. An additional local freshwater demand of about 135 gallons per person per day will be associated with these new residents. This value includes water for households, new commercial development and additional power generation. New water demand for the oil shale industry, new residents and new commerce is likely to be between 160 and 370 MGD or 180,000 to 420,000 acre-ft/yr. **Figure 2** shows the new demand in relation to flows and allocations in the Upper Colorado River basin. Compacts control the amount of water that each state is entitled to use. The compacts allocate between 5.3 and 5.9 million acre-ft/yr of the average annual virgin flow of the Colorado River (15 million acre-ft/yr) to the Upper Basin States of Colorado, Utah, Wyoming[3]. These states used an average of 3.8 million acre-ft/yr of their allocated Colorado River water for the period of 2001-2003[3]. Using the lower allocation number of 5.3 million acre-ft/yr, these three states used 70% of their allocation for this period. In comparison, these states are projected to use 4.8 million acre-ft/yr or up to 90% of their allocated flow in the year 2020[3]. A 2.5 Mmbbl/d oil shale industry will increase these projections by between 0.2 to 0.4 million acre-ft/yr (from **Table 1**).

1 Bartis, J. T., T. LaTourrette, L. Dixon, D. J. Peteson, and G. Cecchine. 2005. Oil Shale Development in the United States; Prospects and Policy Issues. RAND Corporation, Santa Monica, CA.
2 Office of Technology Assessment (OTA). 1980. An Assessment of Oil Shale Technologies. Washington, D.C.
3 DOE/NETL. 2006. Emerging Issues for Fossil Energy and Water; Investigation of Water Issues Related to Coal Mining, Coal to Liquids, Oil Shale, and Carbon Capture and Sequestration. National Energy Technology Laboratory.

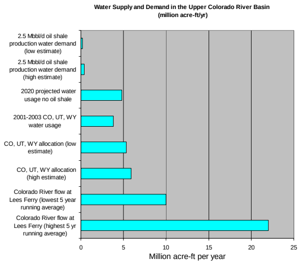

Figure 2. Current and projected water use is shown for the three Upper Colorado River states that fall within the oil shale production region. New water demand for the proposed oil shale industry is shown relative to water use values, and low and high flows measured at Lees Ferry.

Table 1. Water demand for oil shale production and new residents.

Water requirements bbl of water per bbl of oil product	Production rate (Bbl/d)	Water demand for oil shale industry (MGD)	Projected population growth (people)	Additional water to support population growth (MGD)	Total new water demand (withdrawals) (MGD)	Total new water demand (Acre-ft/yr)
1-3	500,000	21-63	96,000	13	34-76	38,100-85,100
1-3	1,000,000	42-126	177,000	24	86-150	96,300-168,000
1-3	2,500,000	105-315	433,000	58	163-373	183,000-418,000

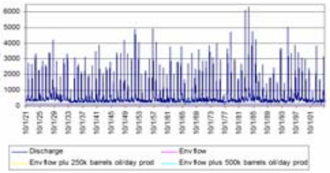

Figure 3. White River flow shown from 1921 to 2005 for the USGS Meeker gaging station.

How does climate variability affect surface water availability?

We performed a threshold-based low flow analysis to answer this question. The analysis examined the duration and frequency of low flow conditions on the White River using the 100 year time series from the USGS Meeker gaging station **(figure 3)**. Low flow events are defined as periods when discharge, Q(t), falls below a specified threshold level, $Q_{0,1,2}$ **(figure 4)**. In this analysis we investigate the impact of oil shale development levels of 250,000 bbl/day (250Mbbl/d) and 500 Mbbl/day, assuming that all the water for this production will be taken from the White River at a rate of 3 bbls of water per bbl of oil produced.

Three thresholds were defined as follows:
Q_0= minimum instream flow + existing uses (200cfs)
Q_1= Q_0 + water for 250 Mbbl/d oil shale production (~250cfs)
Q_2= Q_0 + water for 500 Mbbl/d oil shale production (~300cfs)

Figure 5 shows the duration and frequency of low flow periods for these three thresholds.

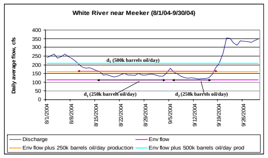

Figure 4. A period of flow from the White River at Meeker hydrograph showing the three threshold values (pink, orange and blue lines) and the duration of low flow periods as defined by the Q_1 and Q_2 thresholds. This particular flow period does not fall below the instream flow threshold, Q_0.

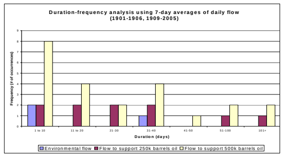

Figure 5. Frequency of low flows (on the y axis) of different duration (on the x axis) for the three thresholds. Blue bars show the frequency and duration of flows below the minimum instream flow requirement, Red bars show flows below the instream flow + 250 Mbbl/day production and Yellow bars show flows below instream flow + 500 Mbbl/day production.

Can we manage surface water resources for oil shale and other uses?

A reservoir analysis was performed to determine if a management strategy could be developed to support new extractions for oil shale. The Sequent Peak method was used to assess the volume of the water deficit that occurs during a low flow period of a given intensity and duration for each threshold. The technique accumulates the amount of flow that falls below the threshold value. The peak of the deficit occurs at the end of the low flow condition, and this peak is approximately equivalent to the size of the reservoir that would have been needed to ensure that the threshold flow requirement was met for that period. **Figure 6a** shows deficit volumes for the three thresholds as a function of time for the 100 year historical flow period. The maximum deficit, W_{max}, for each of the three thresholds falls toward the end of the time series when the White River experienced the lowest flows on record **(figure 6a).** The analysis shows that for the 500K bbl/d production rate case, a 15,500 acre-ft reservoir would mitigate deficits on the White River during the low flow periods within the 100 year flow record.

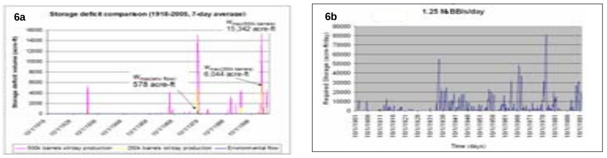

Figure 6a and b. Deficit volumes shown as a function of time for different thresholds. 6a shows the maximum deficit volumes, W_{max}, for thresholds Q_0, Q_1 and Q_2, and the associated reservoir sizes that will mitigate deficits on the river. 6b shows deficit volumes associated with water extractions from the White River to support a 1.25 million barrel per day production rate. The White River would almost always be in a deficit mode for these extraction rates, suggesting that water from other tributary rivers would be required for this higher oil shale production rate .

Conclusion

This analysis suggests that the White River should be able to support new water demands for a 500,000 bbl/d oil shale development if extractions from the river are limited to about 70,000 acre-ft/yr, and an additional 16,000 acre-ft of reservoir capacity is built. Higher extraction rates will result in chronic deficits on the river as shown by **figure 6b**. Although a rudimentary water balance for the greater Upper Colorado River basin suggests that there may be enough water to support a 2.5 million bbl/d oil shale industry **(figure 2)**, the margin of water projected to be available in 2035 will be small. Flows on the Colorado River and its tributaries are already impacted by drought, and are likely to be further impacted by climate change. The analysis also indicates that a regional assessment should be undertaken to quantify the cumulative impacts (in space and time) of the proposed oil shale industry, projected urban growth, and climate change on the water resources of the Colorado River and its tributaries.