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Informing Future Decision-Making on Uranium Mining: A Coordinated Approach to Monitor and Assess Potential Environmental Impacts from Uranium Exploration and Mining on Federal Lands in the Grand Canyon Region, Arizona

Updated March 2014*

A Work Plan Designed to Meet the Requirements of the Federal Record of Decision to Continue Gathering and Assessing Scientific Data that Address Unknowns and Uncertainties Related to Uranium Exploration and Mining Activities during the Withdrawal Period of 2012 to 2032.

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* The Science Plan was updated by USGS in March 2014 after review of empirical data that has become available since the completion of the original science plan (October 2012).

Executive Summary

On January 9, 2012, Secretary Salazar signed Interior's Record of Decision (ROD) to withdraw over 1 million acres from mineral entry under the Mining Law of 1872 (30 United States Code (USC) 22-54), citing several unknowns and uncertainties related to the effects of mining of uranium in the Grand Canyon region (Figure 1; U.S. Department of the Interior, 2012). A key factor in his decision to withdraw federal lands from future uranium mining through 2032 was the limited amount of scientific data available to assess potential impacts, specifically in the terms of groundwater flow paths, radionuclide migration, and biological toxicity pathways.

The withdrawal was subject to valid existing mining rights. As a result, there will be a certain level of mine development going forward. It is estimated that as many as 11 mines, including the four currently approved, could proceed under the withdrawal over the next 20 years.

Federal management in the Grand Canyon region is complex. Section 102(a)(10–12) of the Federal Land Policy and Management Act of 1976 states, "It is the policy of the United States that . . . public lands be managed in a manner which recognizes the Nation's need for domestic sources of minerals . . . including implementation of the Mining and Minerals Policy Act of 1970
. . . as it pertains to the public lands." Section 103(c) provides for a "*combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and non-renewable resources including but not limited to recreation, range, timber, minerals, watershed, wildlife and fish and natural scenic, scientific and historical values; and harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output.*"

To add to the complexity, multiple federal agencies with varying missions are responsible for resources directly or indirectly affected by uranium mining in the Grand Canyon region. Breccia pipe uranium deposits and mines in the area withdrawn are located on Bureau of Land Management (BLM) and USDA Forest Service (USFS) lands. The
BLM's multiple-use mandate includes managing surface acres of public lands and below ground mineral estates for extracted commodities, while providing recreational opportunities for the public. The USFS sustains the health, diversity, and productivity of the Nation's forest and grasslands to meet needs of present and future generations. The National Park Service preserves natural and cultural resources for the enjoyment, education, and inspiration of this and future generations and is concerned that uranium mining may impact the physical, ecological, and human uses of the Grand Canyon watershed and World Heritage-designated Grand Canyon National Park. The U.S. Fish and Wildlife Service is charged with protecting and conserving fish and wildlife resources and has a legal obligation for the protection of migratory birds, endangered species, and their associated habitats. The Service identified 10 listed species in the withdrawal area. The U.S. Geological Survey (USGS), although not a land

management or regulatory agency, is the nation's premier science agency that provides impartial information on the health of our ecosystems and environment, the natural hazards that threaten us, the natural resources we rely on, the impacts of climate and land-use change, and the core science systems that help us provide timely, relevant, and useable information. These federal agencies are cooperating to determine how uranium resources can be developed while minimizing impacts to cultural, environmental, and recreational resources of the Grand Canyon region. This 15-year program describes studies that the USGS can accomplish to reduce the unknowns and uncertainties of uranium mining activity in the region. This information is needed to help the Department determine whether to continue the withdrawal of the lands beyond the current withdrawal period, as well as to inform the permitting of development, mitigation, and reclamation of mines as applicable.

At the onset of this program, the federal government has the unique opportunity to work cooperatively with industry at two mines that will be opened, mined, and reclaimed within the time frame of the withdrawal (2012-2032). However, timing is critical as mining could begin as early as 2013. As guided by the Management Oversight Team (MOT), USGS has identified 19 scientific studies to reduce the unknowns and uncertainties associated with uranium mining on natural resources of the Grand Canyon region. These 19 studies are categorized in the following general themes: genesis of ore, characterization of exposure, pathways of exposure, and biological effects of exposure. Multi-agency investment in this work plan will produce information to help reduce the uncertainty of the environmental impacts of uranium mining and help facilitate future decision-making by the Secretary of the Interior. In addition to meeting the future needs of the Secretary and informing on-going mining activity, the proposed studies will generate information that is expected to provide a wide range of benefits, including:

- Improve the ability to estimate uranium reserves
- Differentiate natural-occurring from anthropogenically-mobilized sources of mining constituents in complex groundwater systems
- Elucidate the primary toxicological exposure pathways of mining to species adapted to arid environments and improved understanding of environmental health risk for such species
- Provide additional information on changes in quality and quantity of biological resources, and the associated ecosystem services, which could be used in future economic analyses.

Estimated costs for the integrated study range from about $2-4M per year for the first 15 years. The following 2 years are used to prepare synthesis documents and are significantly less in costs. The information from this coordinated effort will be produced more cost-effectively as compared to having each agency undertake individual agency- specific studies. The USGS is tasked with conducting the scientific investigations described in this document.

I. Background

The Grand Canyon region has long been recognized as one of the Nation's most treasured landscapes. The Grand Canyon and its surrounding watershed is known as a home or sacred place of origin to many Native Americans, including the Havasupai, Hualapai, Navajo, Hopi, Zuni, Southern Paiute, and others, and its cultural significance goes back thousands of years. Grand Canyon National Park is a World Heritage site and an international icon. It is the cornerstone of the region's economy with hunting, fishing, tourism, and other outdoor recreation generating billions of dollars in economic activity in the area. Millions of people living in seven states in the U.S. and in Mexico depend upon the Colorado River that flows through the region for water for drinking, irrigation, and industrial use, as well as for hydropower. The Grand Canyon region is also believed to contain some of the highest grade uranium ore in the United States. (U.S. DOI ROD: 4-6)

In the late 1940s and early 1950s, uranium was discovered in association with many of the old copper mines in the Grand Canyon region, hosted by geologic features called breccia pipes. Discovery of high-grade uranium ore in the Orphan Lode (breccia pipe) deposit led to uranium mining on patented claims within the Grand Canyon National Park from 1956 to 1969. In the 1970s, breccia pipes became the subject of intense uranium exploration in the Grand Canyon region; several were found exposed in the plateaus and the walls of the Grand Canyon and its tributaries. In the 1980s and early 1990s, uranium was mined from seven breccia pipes in the northern Grand Canyon region. As the price of uranium ore fell in the late 1980s and early 1990s a number of these uranium mines were placed on standby until uranium prices rose again. Beginning in 2004, exploration for uranium ore bodies in the Grand Canyon Region increased significantly as uranium ore prices peaked at over $110 per pound. This flurry of exploration coupled with the renewal of permits to re-open mines on standby raised the concern of resource managers and the public about possible effects on the environment.

On July 21, 2009, the Secretary of the Interior proposed a 20-year withdrawal of about 1 million acres of Federal land near the Grand Canyon from the establishment of new mining claims (Figure 1). The notice of the proposed withdrawal had the effect of segregating the lands involved for up to 2 years from the location and entry under the Mining Law, subject to valid existing rights, while the BLM evaluated the withdrawal application. These lands were contained in three parcels: two parcels predominantly on Bureau of Land Management (BLM) land to the north of the Grand Canyon (North and East Parcels) and one predominantly on the Kaibab National Forest south of the Grand Canyon (South Parcel). The purpose of the notice of the proposed withdrawal and 2-year segregation was to examine the potential effects of withdrawing these areas from the location and entry under the Mining Law for the next 20 years, "to protect the Grand Canyon watershed from adverse effects of locatable mineral exploration and mining, except for those effects stemming from valid existing rights" (U.S. Bureau of Land Management, 2009, p. 43152). The Secretary directed the USGS to conduct a series of short-term studies designed to develop additional information about the possible effects of uranium mining on the natural resources of the region (Alpine 2010). These studies included:

- Estimating the amount of uranium resources within the proposed withdrawal parcels and previously withdrawn areas (Otton et al. 2010a);
- Investigating the effects of the 1980s uranium mine development and extraction operations to determine if mining operations affected local environments (Otton et al. 2010b);
- Examining whether these previous operations were detrimental to the water quality of surface water and groundwater (Bills et al. 2010);
- Compiling toxicological information on exposure pathways and biological effects of uranium and associated decay products relevant to species occurring in the region (Hinck et al. 2010); and
- Completion of a geologic map of the House Rock Valley area (Billingsley and Priest 2010).

Results of these USGS studies along with other studies and resource analyses were included in the environmental impact statement (EIS) developed by the BLM and provided the basis for the final decision regarding whether or not to proceed with the proposed withdrawal or to select an alternative action. On January 9, 2012, Secretary Salazar signed the Interior's Record of Decision (ROD) to withdraw over 1 million acres from mineral entry under the Mining Law of 1872 (30 United States Code (USC) 22-54) for the next 20 years. The Secretary cited several unknowns and uncertainties related to the effects of mining of uranium in the Grand Canyon Region. The Secretary cited that one key factor in his decision to withdraw lands from future uranium mining was the limited amount of scientific data that is currently available to assess potential impacts, specifically in the terms of groundwater flow paths, radionuclide migration, and biological exposure and toxicity pathways.

During the EIS process, BLM formed a federal management oversight team (henceforth, MOT) that included representatives from USFS, Grand Canyon National Park-National Park Service (GRCA-NPS), U.S. Fish and Wildlife Service (FWS), and USGS. The MOT focused on scientific data gaps after the ROD was signed in January 2012 and requested that USGS identify studies to address uncertainties related to the effects of uranium mining in the Grand Canyon Region. On March 22, 2012, the MOT met to discuss the proposed USGS studies and prioritized their importance and urgency by consensus. The MOT then requested USGS to develop this 15 year work plan with the intent that completed priority studies will provide critical scientific information to the Secretary on the impacts both when the mining withdrawal expires in 2032 and throughout the 15-year study period.

II. The Grand Canyon Regional Setting

The Grand Canyon region is unique and complex in terms of its geology, hydrology, and ecology. The area is located within the arid and sparsely vegetated southwest portion of the Colorado Plateau, and characterized by terrain of broad plateaus, ancient volcanic mountains, and deeply dissected canyons (Beus and Morales, 2003). Geologic structures, such as joints, fractures, faults, folds, and bedding planes, control and direct the flow of groundwater movement toward spring discharge areas. Fine-grained sedimentary rocks can inhibit the downward movement of groundwater, resulting in locally perched water-bearing zones, located several hundred to more than 2,000 feet above the underlying regional aquifers.

Fractures and faults in the fine-grained rock units provide pathways for vertical movement of water from the surface and groundwater from the perched water-bearing zones deeper into the subsurface. Dissolution of limestone from groundwater flow through joints and fractures causes caves, caverns, and solution channels to form within these rock layers. The collapse of some of these caves and caverns over time has led to the formation of breccia pipes, some of which host uranium ore deposits. Many of the seeps and springs in the Grand Canyon region emerge from the base of these rock layers. Springs in the area support some of the most diverse habitat of the Colorado Plateau and are a critical source of water for humans, fish, and wildlife. Species diversity in these spring habitats is 100 to 500 times greater than that of the surrounding landscape (Grand Canyon Wildlands Council, 2004). A variety of terrestrial habitats, which result from a wide range of elevation and slope aspect, support diverse flora and fauna that include culturally significant, threatened, and endangered species. Certain areas like the Kaibab National Forest are considered important migration and foraging corridors for various species including pronghorn, mountain lion, elk, mule deer, black bear, northern goshawk, and neotropical migratory birds. Physical disturbances of habitats in this arid environment are often slow to recover and may require long-term commitments from management agencies to ensure the success of ecological restoration.

III. Justification

Investment in the proposed work plan, as informed by the MOT, will reduce the uncertainty of the environmental impacts of uranium mining and help facilitate decision-making by the Secretary of the Interior, now and in the future. Because the impacts of uranium mining do not recognize agency jurisdictional boundaries and all of the affected agencies have an interest in obtaining additional information, this coordinated effort is more cost-effective than having each agency undertake individual agency-specific studies. In addition to meeting the needs of the Secretary, the proposed studies will generate information that is expected to provide a wide range of benefits, including:

- Improve the ability to estimate uranium reserves
- Differentiate natural levels of constituents from mining constituents mobilized from anthropogenic activities in complex groundwater systems
- Prioritize the primary toxicological exposure pathways of constituents to species adapted to arid environments and improved understanding of environmental health risk for those trust resources

IV. Goals and Objectives

The primary goal of this document is to identify critical scientific studies that will reduce the unknowns and uncertainties of uranium mining and inform future Secretarial decisions on whether to continue the withdrawal of the lands beyond the current withdrawal period, as well as to inform the permitting of development, mitigation, and reclamation of mines as applicable. The objectives of the investigations are intended to reduce the unknowns and uncertainties associated with the environmental effects of uranium mining. Specifically, interdisciplinary studies will 1) focus on the genesis and distribution of uranium ore, 2) characterize exposure pathways of mining-related contaminants in water, sediment, soil, and biota, 3) identify and prioritize pathways of exposure to the environment, and 4) determine biological effects of exposure to uranium and other trace elements. Specific mines on BLM and USFS lands will be monitored and assessed during active mining operations but also during pre- and post-mining activities. Such temporal and spatial monitoring at these mines will be designed to evaluate potential impacts to resources in the region and elsewhere.

Ultimately, results of the proposed studies will address how uranium resources on federal lands can be developed to increase this Nation's energy independence, while minimizing potential impacts to other natural resources. By coordinating with the Interior's economists, USGS is working to ensure that the design and implementation of scientific studies can lead to an understanding of the changes in quality and quantity of resources and the associated ecosystem services, which could be used in future economic analysis. In addition, the long-term aspect of these investigations will allow scientists, economists, and resource managers to periodically evaluate study results and to implement adaptive strategies, when needed, to improve the success of this work plan. This coordinated effort relates directly to the DOIs Secretary's priorities of landscape level conservation, stewardship of treasured landscapes, and job creation.

V. Partnering with Industry

The federal government has the unique opportunity to work cooperatively with industry at two mines operated by Energy Fuels Corporation (formerly Denison Mines Corporation) that will be open, mined, and reclaimed during the withdrawal (2012-2032; Figure 2). However, timing is critical for initiating these studies because mining could begin as early as 2017 (Table 1). Canyon Mine breccia pipe is located in the Tusayan Ranger District of the Kaibab National Forest six miles south of Tusayan, Arizona. Surface operations development began in 1986, including a 50 ft collared shaft (Figure 3). The EZ Mine site is located in the BLM's Arizona Strip district west of the Toroweap Road and Hack Canyon (Figure 4). Mining is not expected to begin at EZ Mine site for several years (Table 1). Ore extraction is anticipated to take no more than three years at each mine. No milling will take place at either of these mines; all ore will be hauled to the company's mill facility (White Mesa Mill) in Blanding, Utah (Figure 2). Therefore, reclamation will begin immediately after mine closure at Canyon Mine and EZ Mine site. In addition to these mines and their surrounding habitat, other sites in and adjacent to the withdrawal areas will serve as regional or background sampling locations for surface water, groundwater, sediment, soil, and biological samples.

VI. Description of Proposal Studies

Habitats in the Grand Canyon, its watershed, and its environs support diverse flora and fauna that include culturally significant, threatened, and endangered species. Mining activity can result in changes to this habitat that may increase exposure of water and biological resources to chemical elements including uranium, thallium, radium, and other radioactive decay products, and other toxic trace elements associated with ore bodies such as arsenic, cadmium, copper, lead, mercury, nickel, selenium, thorium and zinc. In addition, water in the Grand Canyon watershed ultimately flows to the Colorado River, a source of recreational water and of drinking water for upwards of 30 million people, and a critical source of agricultural and industrial waters in the Southwestern U.S. Studies designed to prioritize potential routes of exposure include atmospheric dispersion (including wind-borne dusts), aqueous (surface- and groundwater), soil, sediment, and food- chain pathways characteristic of the region are warranted (Figure 5). Characterizing and understanding interrelationships among receptors and these pathways will improve our ability to describe risk at landscape scales and at various levels within the ecosystems of the southwest.

The withdrawal affects a number of federal agencies with varying missions, including BLM, USFS, NPS, and FWS. In addition, several State, local and tribal entities have land-management or regulatory interests. To help meet the future informational needs of these agencies, the USGS has identified 19 tasks designed to better characterize the impact of uranium and other trace element on regional water resources, native flora and fauna, and cultural and recreational uses. When possible, these 19 tasks will leverage expertise from each of the participating agencies.

Tasks are grouped by general themes, which follow a chronological order in terms of exploration and mining: Genesis of ore; Characterization of exposure; Pathways of exposure; and Biological effects of exposure. Numerical designation of tasks in this document are to improve organization and clarity but do not indicate prioritization of individual tasks. Tasks were prioritized as high, medium, or low by the MOT (Table 2). High priority tasks are time critical, require long-term sampling or monitoring, or were previously funded in 2010 and 2011 to address uncertainties associated with uranium mining. Medium priority tasks are also critical, but rely on results from high priority tasks or are not as time sensitive. Low priority tasks rely on results from high and medium priority tasks but are still needed to fully evaluate the impacts of mining on the environment in the Grand Canyon region.

1) Improve Understanding of the Genesis of Ore

The genesis of ore deposits in breccia pipes is poorly understood and the number of mineralized breccia pipes in the Grand Canyon region is currently unknown. Comparing the age, geochemistry, minerology, and other geologic characteristics of the breccia pipe uranium ores and nearby sandstone-hosted uranium ore deposits will help determine if these mineralizing events are related in time and space. Determining the relationship, if one exists, expands our ability to predict areas most likely to host yet-to-be discovered uranium deposits in the region. Applying generic models to estimate the number of breccia pipe ore deposits results in large uncertainty in uranium resource estimates. Uncertainty of resource estimates in the region can be minimized by improving our geologic and hydrologic understanding of the origin, distribution, and geochemistry of ore deposits (Table 2).

To decrease uncertainty associated with the genesis of ore deposits in breccia pipes, we propose to:

- Evaluate the distribution and stratigraphic positions of uranium ore-bearing breccia pipes across the Grand Canyon Region to consider possible geologic controls on their formation and ultimate distribution. Results of this study will improve the ability of USGS to make a much more refined estimate of the potential uranium resources in the region. In addition, ongoing geochemical studies of ore materials will be supplemented with isotopic analyses including sulfur isotopes and Uranium-Lead age determinations to improve our understanding of the origin of ores. (**Task 1**; *see Table 2 for priority and Table 3 for* *estimated cost for each task*)

- Estimate the number of buried and concealed mineralized breccia pipes using existing geologic maps and research findings, as well as through cooperation with mining companies to use geophysical, drilling, and exploration data. Results of this study will improve the ability of USGS to make a much more refined estimate of the potential uranium resources in the region. (**Task 2**)
- Evaluate the potential role regional hydrology had on breccia pipe mineralization (hundreds of millions of years ago) by reconstructing the geologic and paleohydrologic setting that existed during ore formation. (**Task 3**)
- Evaluate the mineralogy, chemistry, isotopic character, and age of breccia pipe ore deposits. This study will refine the genesis model for the breccia pipes and their distribution of hidden ores. (**Task 4**)

2) Characterization of Transport pathways of mining related contaminants in water, soil, sediment and biota

Uranium and other chemical constituents associated with breccia pipe deposits occur naturally in soil, sediment, groundwater, and surface water from the weathering and leaching of ore deposits. Mining of breccia pipes has the potential to enhance release of chemical constituents (such as uranium and associated trace elements) into the environment, which can then expose soil, water and biological resources to mining-related contaminants. Determining the relative contribution of radiation and chemical constituents in water and biological resources from mining activities is problematic and challenging without an understanding of background concentrations. The potential for increased exposure resulting from mining activities has not been well characterized in the Grand Canyon region because regional/background concentrations of uranium and other trace elements in water, sediment, soil, and biota are largely unknown and there is a general lack of understanding regarding the local and regional groundwater flow systems. Water can move through breccia pipes into deeper aquifers naturally, but water movement is not well characterized once a pipe is opened for mining. In addition, relative contributions of uranium and other trace metals introduced into the environment from natural sources compared to sources enhanced by anthropogenic activities (e.g., mining) is poorly understood. Determining how mining-related chemical constituents move through the environment will allow future mining operations to be designed to minimize exposure and potential impacts to water and biological resources (Table 2).

To improve characterization of exposure to mining-related contaminants, we propose to:

- Determine regional/background concentrations of uranium and other trace elements and radiation levels in water, sediment, soil, and biota (vegetation, invertebrates, amphibians, reptiles, birds, and small mammals). A coordinated sample design of each media type will allow for results to be incorporated into an integrated data analyses for environmental risks. Resources to be sampled throughout the region include surface water and sediments from intermittent and perennial streams and spring sources; groundwater from wells; soils from non-mined areas; and biota with a focus on federal trust resources from non-mined areas. Surface water from tributaries to the Colorado River from Lees Ferry to Lake Mead, Arizona will be used to improve characterization of natural and anthropogenic sources of uranium and other trace elements. Periodic re-sampling will be conducted as needed to account for seasonal influences on concentrations. Existing stream and spring flow and water-chemistry data from BLM, USFS, NPS, and USGS will also be used. Finally, potential flood routing and mass-balance scenarios of flash flood events will be evaluated as well as re-evaluating historic events, where possible. Results from these efforts will help quantify uncertainties associated with exposure matrices (soil, sediments, surface water, or groundwater) that likely affect biological resources and other ecosystem components at risk. (**Tasks 5 and 12**)

- Characterize the water chemistry associated with a breccia pipe mine and a naturally exposed mineralized ore body, which will be considered the reference standard for comparison of mine impacts. Sampling will take place before, during, and after a precipitation event at a previously mined uranium mine site and selected nearby springs to improve our understanding of breccia pipes as potential transport mechanisms for water from the surface to water-bearing zones at depth and for changes in water chemistry to exposed ore. (**Task 6**)
- Conduct habitat and species surveys (including threatened and endangered species, NPS species of management concern, BLM species of concern, and USFS species of concern) in and adjacent to the Canyon Mine and EZ Mine site before mining starts, during active mining, and after mine remediation to determine the degree that biota occur near and are attracted to mining activities. Results from this study will help identify species for radiation and chemical characterization and will therefore help bound uncertainty in the ecological risk analysis. (**Task 7a**)
- Characterize concentrations of uranium and other trace elements and radiation levels in water, sediment, soil, and biota (including federal trust resources) in and adjacent to the Canyon Mine and EZ Mine site before mining starts, during active mining, and after mine remediation. Sampling before, during, and after precipitation events will also occur. (**Tasks 7b and 7c**) Deeper horizons of soils and sediment deposits in washes will be analyzed to characterize the vertical distribution of uranium and other trace elements to provide information on the soil profile to depths of burrowing animals that may potentially be affected by mine operations. Overall, results from this study will determine if temporal changes in radiation and chemical concentrations in various media during the mine life cycle result in greater exposure and thus risk to the surrounding environment. (**Task 7d**)
- Continue to evaluate and refine the isotopic Uranium Activity Ratio (UAR) analysis in water, and ore samples from historical and active mines (**Task 8a**). This study will help determine if the mobility of uranium and other trace elements is enhanced by mining activities and delineate natural versus anthropogenic sources of uranium in the region.
- Drill and develop observation wells into the regional aquifer at strategic locations within the withdrawal area (a minimum of two on the north parcel and one on the south parcel). These new observation wells will be located with consideration to existing wells that may be available for monitoring purposes and groundwater monitoring wells developed by the mining company at Canyon Mine and EZ Mine site. Data from new observation wells and existing wells will improve our understanding of local and regional groundwater flow, including better defining groundwater divides, and water-chemistry transport in the Grand Canyon region. (**Tasks 5b, 9 and 10**)
- Update the Northern Arizona Regional Groundwater Flow Model (NARGFM) so that it

can be refined to the degree it can be used as a transport model to help evaluate the local and regional groundwater flow for the past several decades as it affects the transport of solutes and different elements from source areas (natural or mined ore bodies) to discharge areas (springs or the Colorado River). This model will be used to evaluate flow and water chemistry changes decades into the future based on projected mining activity. **(Task 10)**

3) Determine Pathways of Exposure

Although breccia pipe mines generally have a small footprint, the scale of environmental risk is not necessarily directly proportional to footprint, particularly when exposure pathways are considered at landscape scales and ecosystem levels of organization. Mining and extraction of uranium ore from breccia pipe deposits can result in transport of chemical constituents via dissolution, seeps/springs, erosion (wind, runoff and floods) and deposition, and biotic uptake. Pertinent ecological exposure pathways from this secondary contamination include ingestion, inhalation, absorption, biotic uptake, and cell membrane mediated uptake. Prioritization of these exposure pathways is critical to understand where mitigation measures could be applied to minimize exposure and therefore potential risk to radiological and chemical constituents (Table 2).

To prioritize exposure pathways associated with mining-related contaminants, we propose to:

- Characterize the dispersion characteristics of uranium and trace elements associated with uranium mining and the subsequent risk to biota by installing dust collectors in the vicinity of ore bodies, mines, and at sites unaffected by uranium ore contamination. Sampling at Canyon Mine and EZ Mine site will be conducted before mining starts, during active mining, and after mine remediation. Data will be used to quantify risks caused by the chemical or radiation releases linked to uranium mining. This study will reduce uncertainty of the location and degree of dust and contaminant dispersion by wind related to uranium mining activities. (**Task 11**)
- Monitor surface waters to determine the mobility and flux of uranium and other trace elements in drainages with historical and current mining. This study will use existing stage sensors (streamflow) and automatic-samplers to collect water samples during runoff events in Kanab Creek (north parcel) and Havasu Creek (south parcel), areas with ongoing and planned mining, for laboratory analysis of dissolved and suspended uranium and selected trace elements; upstream runoff samples will be collected for comparison. The Colorado River at Lees Ferry and above Diamond Creek will be sampled on a quarterly basis during the withdrawal period. Water samples will be collected over a range of flows including reservoir releases from Glen Canyon Dam and also during tributary inputs from the major tributaries. These tasks are a continuation of ongoing monitoring and sampling at these sites that will better quantify the transport of uranium and other trace elements through the regional surface water system. Periodic sampling during runoff events in intermittent and ungaged washes on the north and south parcels where historic mining has occurred (Hack Canyon, Cottonwood, Horn and Johnson Washes) and where mining will occur will help to characterize chemical constituents in regional surface waters. To the extent possible, monitoring will be done at these sites prior to mine development, during the life of the mine and after mine reclamation. Technical findings from this study will better characterize

uncertainty for dispersion events associated with naturally occurring weather events, including extreme events such as storms and subsequent flooding. **(Task 12)**

- Evaluate scenarios of impact from potential overflowing of wastewater containment ponds or disturbance of waste rock resulting from precipitation or flash flood events that overwhelm a mine site and subsequent risk to biota. These will be opportunistic sampling events at Canyon Mine and EZ Mine sites and ongoing at the reclaimed Hack mines. This study will help characterize contaminant transport off-site in terms of quantity and distance and their associated risk to desert flora and fauna. **(Task 13)**
- Determine the fluxes and storage of uranium and other trace elements in Lake Mead sediments. This study will analyze archived sediment and core samples collected by USGS from the Virgin River Arm of Lake Mead for uranium, radium, thorium, and cesium and selected trace metals. Additional sediment and core samples from the delta of the Colorado River inflow area to Lake Mead will also be collected and analyzed. The mobility of contaminated sediments and the implications to the water supply will be evaluated using flux calculations. This study is important because as water levels in Lake Mead fluctuate, the potential for dissolution and mobilization of uranium and other trace elements attached to delta sediments increases. **(Task 14)**

4) Determine Biological Effects of Exposure to Contaminants

By prioritizing the relative importance of various exposure pathways identified above, the biological effects of exposure can be examined to determine if mining-related contaminants or activities are adversely affecting federal trust resources. There is very little chemical contamination data related to uranium mining for biota in the Grand Canyon region. Many species in the region have specialized life history strategies that allow them to survive in the arid environment but that may also increase their exposure to contaminants. For example, some reptiles, amphibians, birds, and mammals spend significant amounts of time in burrows, where they may inhale, ingest, or absorb uranium and other contaminants while digging, eating, preening, and hibernating. As such, existing toxicity effect thresholds developed using common laboratory test organisms may have limited applicability given the unique physiology and behaviors of species inhabiting the Grand Canyon region. Therefore, laboratory studies with native species or appropriate surrogates are warranted to reduce uncertainty associated with the biological effects of exposure (Table 2).

- Quantify the risk to native flora and fauna caused by chemical or radiation releases linked to uranium mining. We will conduct an ecological risk analysis integrating data from previous studies in this plan (Study 1-14), with a focus on temporal changes in risk based on data from before mining began, during active mining, and after mine reclamation. Results from this study will determine which exposure pathway and constituent(s) (e.g. uranium, arsenic, cadmium, and radiation) drive the risk to biological receptors. **(Task 15)**
- Develop radiation and chemical effect thresholds of uranium for biota inhabiting mining areas of the Grand Canyon region. A controlled acute laboratory exposure to environmentally relevant concentrations of uranium will be conducted on native biota or appropriate surrogates. Species selection will be determined by results of the species

surveys previously described. Threshold concentrations for adverse effects such as growth, development, reproduction, and immune suppression in biota will be determined. Results of this study will develop acute toxicity thresholds for native flora and fauna to uranium, thereby reducing the uncertainty associated with risk estimates based on surrogate species. **(Tasks 16a, 16b)**

- Characterize the risks to biota chronically exposed to uranium such as genetic effects on species populations, density, ecosystem dynamics, and biodiversity. A controlled chronic laboratory exposure to environmentally relevant concentrations of uranium in water and in soil, sediment and diet will be conducted on native biota or appropriate surrogates. Species selection will be determined by results of the species surveys previously described. Threshold concentrations for adverse effects such as growth, development, reproduction, and immune suppression in biota will be determined. Results of this study will develop chronic toxicity thresholds for native flora and fauna to uranium, thereby reducing the uncertainty associated with risk estimates based on surrogate species. **(Task 16c)**
- Evaluate the effects (synergistic, additive, antagonistic) of chemical exposure of uranium to other metals, semi-metals, and other toxic compounds common in breccia pipes including arsenic, selenium, copper, nickel, lead, and zinc. A controlled laboratory exposure to environmentally relevant concentrations of contaminant mixtures will be conducted on native biota or appropriate surrogates. Species selection will be determined by results of the species surveys previously described. We will determine threshold concentrations for adverse effects such as growth, development, reproduction, and immune suppression in biota. No observable adverse effect concentrations (NOAEC) and lowest observable adverse effects concentrations (LOAEC) will be determined. Results from this study will determine if chemical mixture have increased toxicity to biota compared to the toxicity of individual constituents. In addition, we will conduct studies to determine the levels of bioaccumulation of uranium and associated trace elements in resident organisms across existing levels of uranium concentrations. **(Task 17)**
- Evaluate the risk of radiation exposure for trust resources that spend prolonged periods of time (e.g. hibernation, avoiding heat of the day) in the subterranean environment. A controlled laboratory exposure to environmentally relevant levels of radiation will be conducted on native biota or appropriate surrogates. This study will determine if the life history strategies and physiological adaptations of burrow animals leads to increased radiation exposure and potential effects. **(Task 18)**
- Determine the sensitivity of native wildlife receptors to chemical and radiation exposure encountered in the field because of the lack of radionuclide toxicity data for most biological receptors. A controlled chronic laboratory exposure to environmentally relevant concentrations of uranium and radiation will be conducted on native biota and common toxicity test organisms. Species selection will be based on results of toxicity threshold studies described previously. **(Task 19)**

VII. Coordination of USGS Studies with Potential Economic Analysis

Though not explicitly addressed in this work plan, the Department's economists have identified additional work that could be conducted to complement the proposed scientific studies. In general, stakeholder values may be affected by changes in land management, including whether to mine or withdraw in the future. While some of the resources related to the withdrawal can be quantified and monetized relatively easily (e.g., the value of uranium ore mined), other resources (e.g., the values associated with potential impacts on cultural resources) are less easily monetized. Just as there are opportunities to collect significant scientific information from the two mining sites, economic information could also be collected for future benefit-cost analyses. USGS' scientific output from the mine site studies could be developed as measures of ecosystem services for use in economic analyses on the effectiveness of mitigation, reclamation, and restoration. If industry is willing, additional information on private mitigation costs would be useful for future economic analysis. With respect to the withdrawal area, it will be valuable to track recreation use within the withdrawn area over time. There will be no way to reliably evaluate the extent to which uranium mining might impact visitation to the Grand Canyon without on-site visitor surveys. A benefit-cost analysis will also need information about uranium demand and supply, and especially about the responsiveness of both to price changes. While there are a variety of options, development of an integrated assessment between the proposed USGS studies and economic analyses would be the best approach to cost-effectively provide the full range of information needed for future decision-making.

VIII. Timeline and Budget Estimates

The timeline is based on the task prioritization, which was one outcome of the MOT meeting held on March 22, 2012. The timeline for tasks begins in FY2013 and ends in FY2027, which leaves 2 years for data synthesis into a final report and an additional 3 years for an economic analysis report before the withdrawal expires in 2032. Periodic progress reports will be produced during the life of the tasks. A final synthesis report will be the primary document that the Secretary of the Interior and cooperating agencies will reference to determine future management of the withdrawal area by 2032.

The costs for conducting the 19 tasks to address unknowns and uncertainties related to mining uranium from breccia pipes in the Grand Canyon Region is estimated to be about $2-4M per year for the first 15 years; the subsequent 2 years are reduced in costs and reflect final summary report (table 3). However, detailed scopes of work have not been developed for individual tasks given the short timeframe granted for developing this overall framework. Costs are estimated on the basis of extensive experience of the USGS principal investigators conducting similar studies. Monitoring and analysis and associated costs occurring FY2012 are not included in tables 2 and 3. Estimated annual costs may vary depending upon activities associated with mining operations. Completed research will undergo periodic review to allow for course corrections in research directions and budget projections. It is possible and even likely that the timing and costs of each of the tasks will differ from what is presented in table 3 as more knowledge is gained during the program and adjustments to the program are made. There are a number of options to facilitate equitable cost-sharing of this unique, long-term opportunity for significant research that could be explored.

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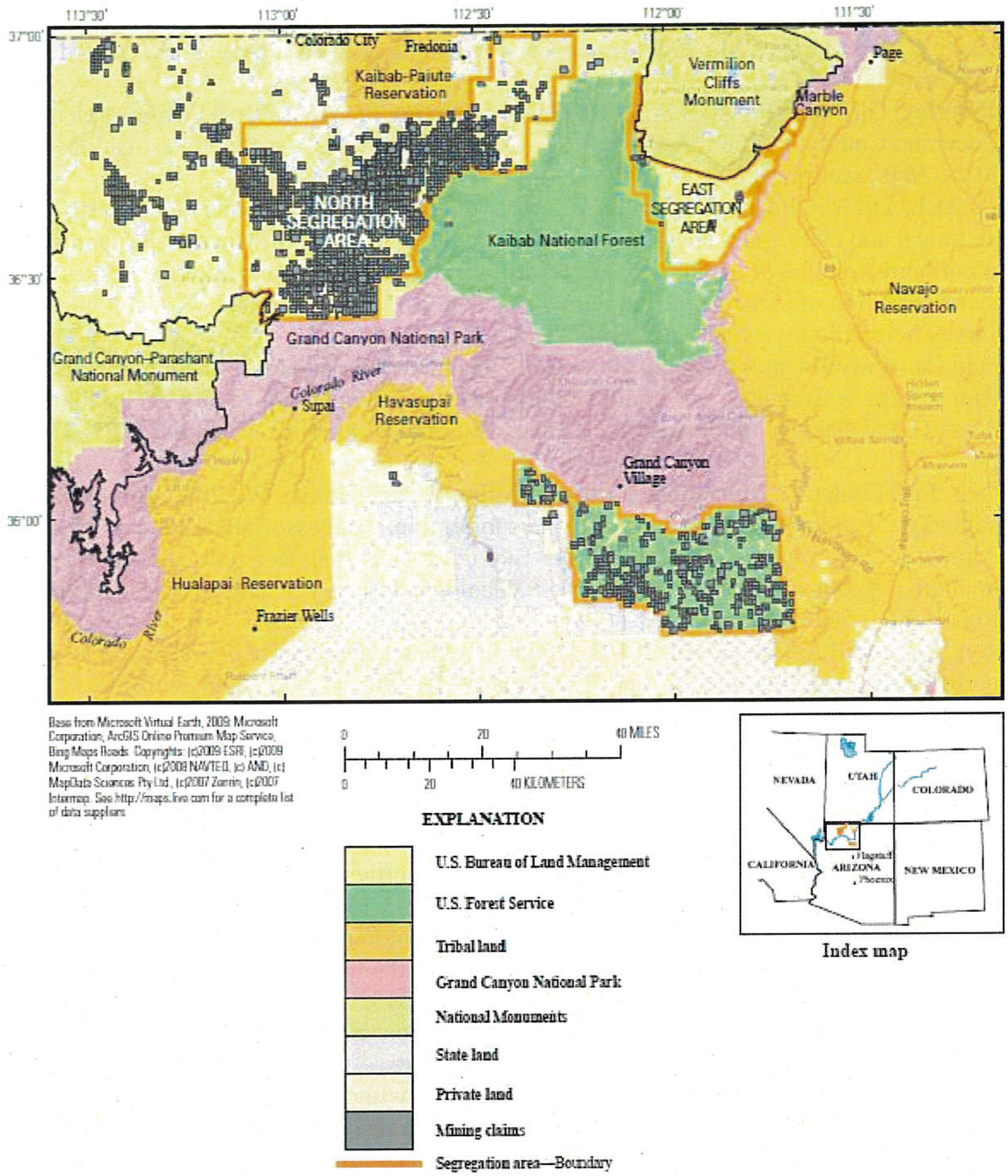

Figure 1. Map showing land ownership and mining claims in and near the North, East, and South Parcels (formally called Segregation Areas). From Otton et al. 2010a.

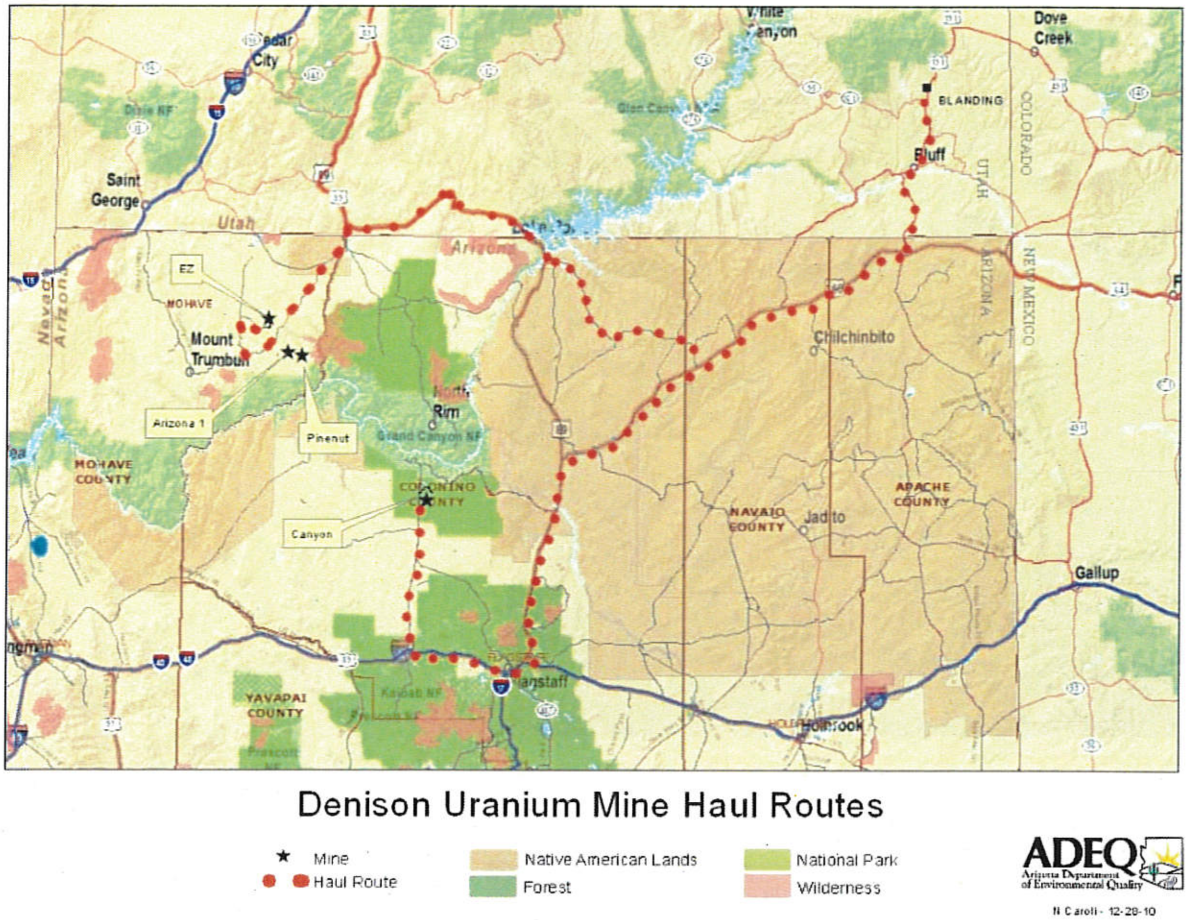

Figure 2. Map of Canyon Mine and proposed EZ Mine site and primary haul routes in the Grand Canyon region.

Figure 3. Canyon Mine, Arizona in 2010. (Google Earth Image, downloaded May 1, 2012)

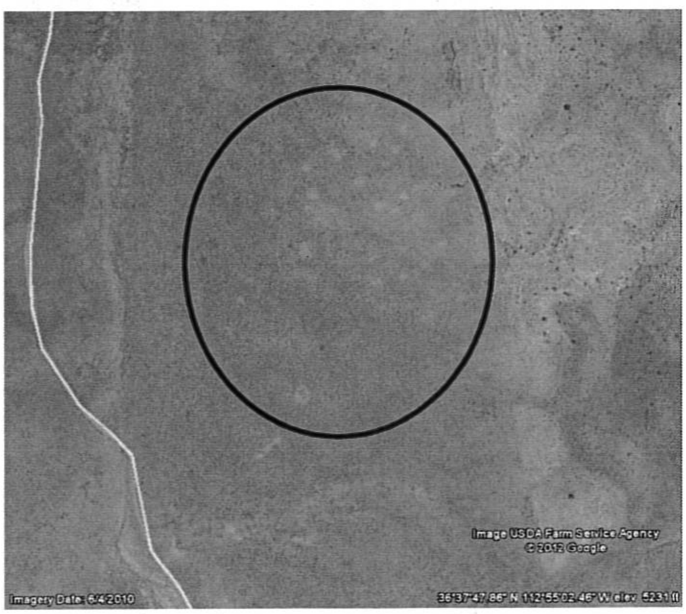

Figure 4. EZ orebody (proposed mine site), Arizona area in 2010. (Google Earth Image, downloaded May 1, 2012)

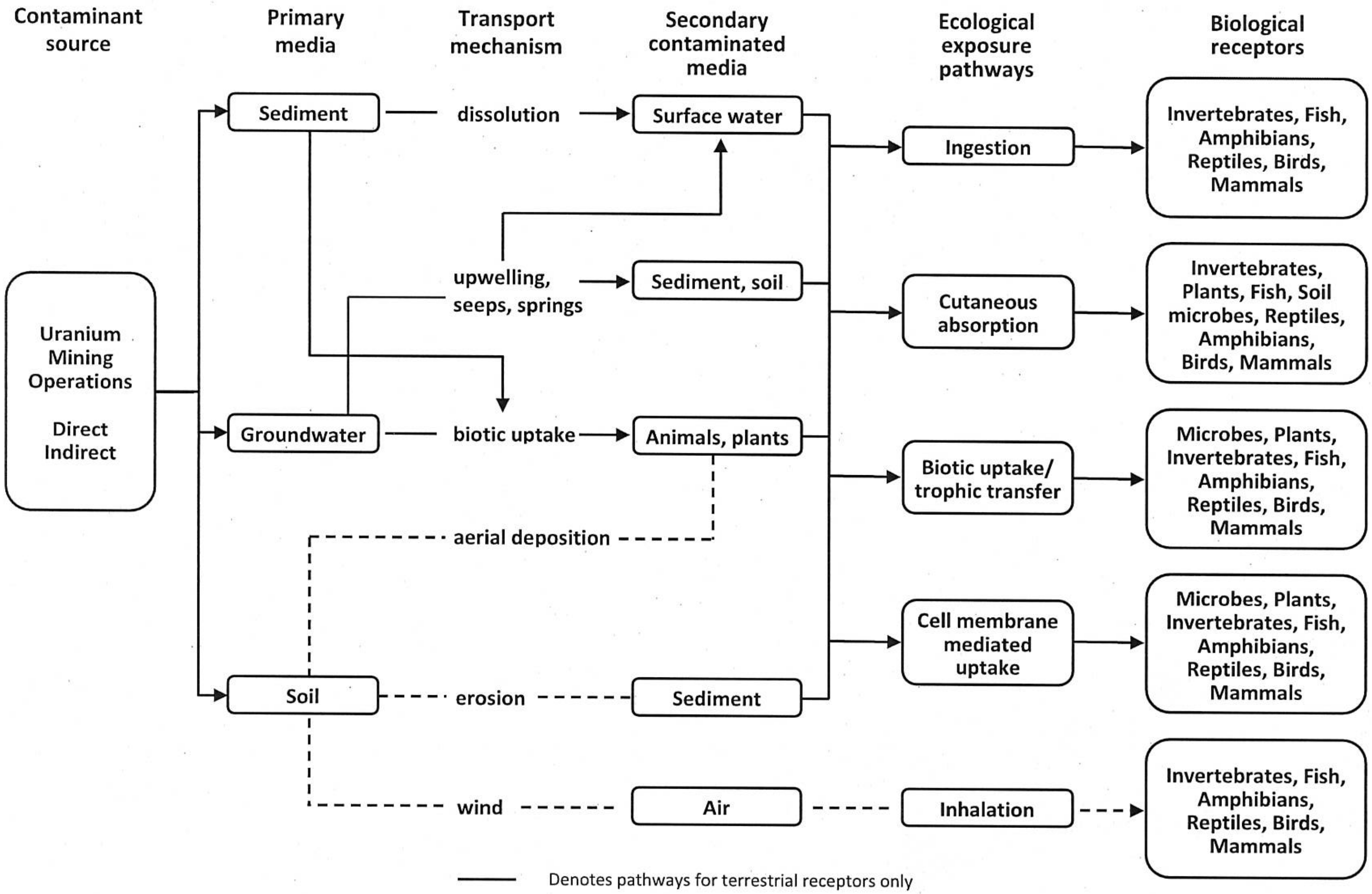

Figure 5. Exposure pathways between generalized terrestrial and aquatic habitats.

Table 1. Conceptual schedule of mining activities at Canyon Mine and EZ Mine site to show timing between mines and throughout the withdrawal period.

Mine activity	Estimated timing (Year)														
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Canyon Mine															
Mine development (dig shaft, construct facilities, power lines, etc.)	■														
Mine operations (extraction to transport to milling facility)[a]	■	■	■	■											
Mine closure					■										
Remediation					■	■	■								
Restoration - Natural and Active (into perpetuity)						■	■	■	■	■	■	■	■	■	■
EZ Mine site															
Mine development (dig shaft, construct facilities, power lines, etc.)				■	■										
Mine operations (extraction to transport to milling facility)[a]						■	■	■							
Mine closure									■						
Remediation									■	■	■				
Restoration - Natural and Active (into perpetuity)										■	■	■	■	■	■

[a] No milling will be conducted on-site.

Table 2. Tasks designed to address uncertainties associated with the effects of uranium mining in the Grand Canyon region and listed by priority as determined by the Management Oversight Team (Meeting held March 22, 2012). Task numbers in parentheses match those in the text and on Table 3.

	Genesis of Ore	Characterization of Exposure	Pathways of Exposure	Biological Effects of Exposure
High Priority	• Distribution and stratigraphic position of breccia pipes (Task 1) • Number of mineralized breccia pipes (Task 2)	• Determine regional/background concentrations for radiation and chemical constituents in water, sediment, soil, and biota (Task 5) • Compare water transport mechanisms in mined and un-mined breccia pipes (Task 6) • Determine concentrations for radiation and chemical constituents in water, sediment, soil, and biota in and adjacent to Canyon Mine and EZ Mine site before, during, and after mining, including long term monitoring (Task 7a-c) • Differentiate natural from anthropogenic uranium sources (Task 8) • Drill and develop groundwater monitoring wells (Task 9)	• Characterize wind dispersion of chemical constituents in and adjacent to Canyon Mine and EZ Mine site before, during, and after mining, including long term monitoring (Task 11) • Surface water monitoring chemical constituents in Kanab Creek, Havasu Creek, and Colorado River (Task 12a/b)	• Conduct integrated ecological risk analysis (Task 15) • Characterize risk to biota chronically exposed to uranium (Task 16c)
Medium Priority		• Update regional groundwater model and test generic models to evaluate effect of down cutting of the Colorado River on regional hydrology (Task 10) • Collect/analyze soils including deeper horizons to characterize vertical distributions (Task 7d)	• Surface water monitoring of intermittent washes during runoff events (Task 12c) • Analyze archived Colorado River delta sediments from Lake Mead inflows (Task 14a)	• Develop radiation and chemical effect thresholds of uranium for native biota (Task 16a/b)
Low Priority	• Role of hydrology in breccia pipe mineralization (Task 3) • Compare breccia pipe deposits to sandstone deposits (Task 4)		• Evaluate scenarios of impact from overflowing wastewater ponds or disturbance of waste rocks from runoff events (Task 13) • Collect and perform chemical analysis on sediments from Lake Mead inflow (Task 14b)	• Determine biological effects of uranium + trace element mixtures (Task 17) • Evaluate radiation risks to biota using subterranean habitats (Task 18) • Determine sensitivity of native wildlife receptors to chemical and radiation exposure (Task 19)

Table 3. Estimated costs (in thousands) for long-term monitoring, data collection, and reporting, 2013 - 2029.

(Note: Colors designate the priority of each task as determined by the Management Oversight Team (High, black; Medium, gray; Low, white)

Category and Study									Yea
	2013	2014	2015	2016	2017	2018	2019	2020	202
Genesis of Ore									
1. Distribution and stratigraphic positions of breccia pipes	$17	$23							
2. Estimate the number of mineralized breccia pipes		$40	$17						
3. Role of hydrology in breccia pipe mineralization								$60	
4. Compare breccia pipe to sandstone deposits								$96	
Characterization of Exposure									
5. Determine regional/background concentrations for radiation and chemical constituents in water, sediment, and biota									
5a. Compile/evaluate existing and newly collected monitoring data from various agencies/sources	$68	$69	$70	$71	$82	$78	$73	$75	$7
5b. Collect/analyze water and sediment samples from streams and springs	$170	$172	$174	$178	$204	$193	$183	$185	$18
5c. Collect/analyze samples from biota with focus on trust resources	$170	$172	$174						
6. Compare water transport mechanisms in mined and unmined breccia pipe	$159	$160	$163	$166	$186				
7. Determine concentrations for radiation and chemical constituents in water, sediment, soil, and biota in and adjacent to Canyon Mine (start 2013, end 2016) and EZ Mine (possible start 2016, end 2019) before, during, and after mining (assumes 2 years mining followed immediately by reclamation plus post-reclamation monitoring at year 5)									
7a. Conduct species surveys	$57	$57		$119	$66		$59		$3
7b. Collect/analyze water and sediment samples	$79	$80		$166	$93		$83		$4
7c. Collect/analyze samples from biota with focus on trust resources	$227	$229		$475	$265		$237		$12
7d. Collect/analyze soils including deeper horizons to characterize vertical distributions	$57	$57		$119	$66		$59		$3
8. Differentiate natural from anthropogenic uranium sources									
8a. Continue evaluation/analysis of Uranium Activity Ratio analysis	$51	$51	$52	$53	$60	$56	$53	$54	$5
8b. Continue evaluation/analysis of ore geochemistry from historical and active mines	$113								
9. Drill and develop groundwater monitoring wells	$2,267	$2,288	$2,326	$1,188					
10. Update regional groundwater model					$133	$63	$59	$60	$6
Pathways of Exposure									
11. Characterize wind dispersion of chemical constituents in and adjacent to Canyon Mine (start 2013, end 2016) and EZ Mine (possible start 2016, end 2019) before, during, and after mining (assumes 2 years mining followed immediately by reclamation plus post-reclamation monitoring at year 5) and non-mined sites by installing of dust collectors	$340	$172	$174	$178	$199	$188	$178	$181	$18
12. Surface water monitoring chemical constituents in drainages with historical and current mining									
12a. Determine flux and transport in Kanab and Havasu Creeks	$198	$200	$204	$208	$239	$226	$213	$217	$21
12b. Determine flux and transport into the Colorado River	$136	$137	$140	$143	$163	$154	$146	$148	$14
12c. Determine flux and transport of intermittent, ungaged washes sampling	$68	$69	$70	$71	$82	$78	$73	$75	$7
13. Evaluate scenarios of impact from overflowing wastewater ponds or disturbance of waste rocks from runoff events (opportunistic at Canyon Mine or EZ mine)	$28			$30					
14. Determine flux and storage of chemical constituents in Lake Mead sediments									
14a. Analyze archived Colorado River delta sediments from Lake Mead inflows	$34								
14b. Collect/analyze Colorado River delta sediments from Lake Mead inflows					$199	$188			
Biological Effects of Exposure									
15. Conduct ecological risk analysis integrating all data from previous studies in this plan		$131	$131	$131					
16. Develop radiation and chemical effect thresholds of uranium for native biota									
16a. Laboratory studies for chemical effect thresholds of uranium for multiple species						$501	$474	$481	$48