Leking, Geoffrey R, EMNRD

From:	Randall Hicks <r@rthicksconsult.com>
Sent:	Tuesday, June 17, 2014 11:01 PM
To:	Leking, Geoffrey R, EMNRD; Bratcher, Mike, EMNRD; Griswold, Jim, EMNRD
Cc:	kristin@rthicksconsult.com; mike@rthicksconsult.com; dale@rthicksconsult.com; andrew@rthicksconsult.com; david@rthicksconsult.com
Subject:	Pit Closure - Geomembrane over the Pit Footprint or over Stabilized Cuttings only?
Attachments:	UnsaturatedFlowandGeomembraneCoversFINAL.pdf; ContractorClosureInstructions06 10 14.pdf

Geoff-Mike-Jim

I suggest you read the attachment "when you have the time".

This is an informal submission that explains how the closure process can work. We promised to submit this memo at our meeting in the field a few weeks back.

The operators and RT Hicks are prepared to lay a new, welded seam liner over the entire pit footprint, if that is what OCD believes is what is best for the environment. There is no material cost differential between what we believe is best for the environment and covering the entire footprint. Of equal economic importance to me, I am done fighting this battle with no compensation.

I believe that the pits that do not have a geomembrane cap and soil cover are "closed" but not reclaimed – so perhaps the operator is in full compliance with the Rule even though 9 months between rig release and the soil cap may exist for a few pits in a few weeks. So we may have some time to allow a good physicist to examine the Newtonian Mechanics (gravity, capillary forces, entropy and liner degradation) of this submission and work with you all to implement a policy that is good for the environment and consistent with the Rule.

Have fun with this and call me with questions.

Randall T. Hicks
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Seepage into Waste - Vertical Migration Through Unlined Dike Into Waste And Through Future Cracks/Holes In Liner

Below are two conceptual examples that illustrate the downward and lateral migration of moisture from the ground surface. To better understand unsaturated flow mechanics (and this discussion) we recommend an excellent 24-page primer on unsaturated flow provided in a USGS publication http://wwwrcamnl.wr.usgs.gov/uzf/abs_pubs/papers/nimmo.05.uzflowproc.ehs.hsa161.pdf.

Minimum Seepage Case Scenario – No Flux/No Solute Transport Up or Down

This scenario requires compliance with the Pit Rule. Specifically

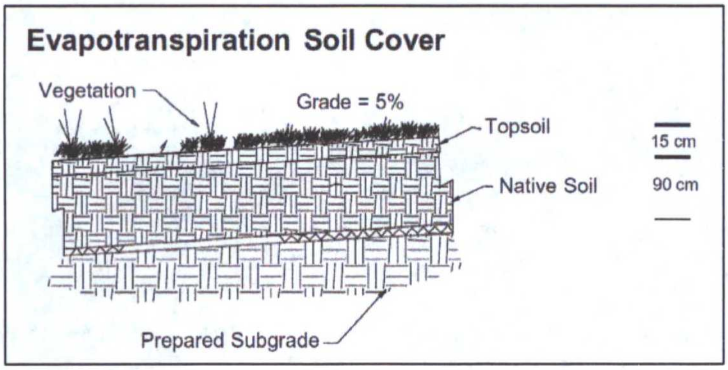
1. One-foot of topsoil (or "suitable material"), which includes organic matter, sand, clay, degraded caliche. The topsoil is finer-grained than the underlying soil cover and is similar to a sandy loam.
2. Beneath the topsoil is at least 3 feet of clean, earth material. This material is typically caliche, dune sand or sometimes bedrock (claystone, limestone, gypsum or sandstone).
3. The graded ground surface over the stabilized material is sloped to prevent ponding of water and erosion of the cover material
4. A plant cover of at least seventy percent (70%) of pre-disturbance levels covers the area of the reclaimed pit site.

If an operator meets this compliance with the Rule, modeling of unsaturated flow and measurement of moisture flux in the Permian Basin show that the movement of water at the 4-foot depth level is so small as to be nil. A Geomembrane cover is not technically required where an operator is fully compliant with the mandates of the Rule.

This was the argument put forward in the Pit Rule testimony by several NMOGA experts: compliance with the Pit Rule mandates described above obviates the need for a Geomembrane liner. There are many peer-reviewed professional papers that discuss the movement of moisture in the arid west and support this "minimum seepage" scenario of "effectively zero movement of water, up or down, at a depth of 4-feet beneath a sloped, vegetated surface". A few of these papers are listed below.

Research

The paper written by Dwyer and Revis (Alternative Landfill Cover Demonstration, FY 2000 Annual Date Report, http://www.sandia.gov/caps/alternative_covers.pdf) discusses the moisture migration beneath several different landfill cover designs at Sandia National Laboratories in Albuquerque, NM. With respect to the soil and Geomembrane cover above stabilized drilling waste, the evaluation of the Evapotranspiration Soil Cover is most germane.



As shown in the graphic, the ET Soil Cover is very similar to the mandated soil cover in the Pit Rule. However,

- a 5% grade is not mandated by the Rule, but the provision to prevent ponding is mandated.
- The 15 cm of topsoil (6 inches) in the described experiment is half of what is required by the Pit Rule.
- The 90 cm (3 feet) of native soil (or clean fill) is less than what is mandated by the Rule. The "prepared subgrade" is not defined, but since the monitoring of moisture flux takes place above the subgrade, the nature of this material is not important to the findings.

The moisture flux of the ET Soil Cover as compared to other tested covers is presented below.

Table 4. Flux Rate Values of Test Covers at the ALCD Site

Year	Flux rates (mm/year)					
	Subtitle D	GCL	Subtitle C	Capillary Barrier	Anisotropic Barrier	ET
1997 (May 1 - Dec 31)	10.62	1.51	0.12	1.62	0.15	0.22
1998	4.96	0.38	0.30	0.82	0.14	0.44
1999	3.12	4.31	0.04	0.85	0.28	0.01
2000 (Jan 1 - Jun 25)	0.00	0.00	0.00	0.00	0.00	0.00
Average	4.82	1.81	0.13	0.87	0.16	0.19

The ET test cover performed very favorably, as can be readily seen by the declining 3-year flux rate: from 0.22 mm/year to 0.01 mm/year. Because the data from 2000 stops prior to the typical monsoon months, the flux rate is not comparable to the remainder of the table.

Similar results can be found in the following publications:

- Evaluation of Evapotranspirative Covers for Waste Containment in Arid and Semiarid Regions in the Southwestern USA http://www.beg.utexas.edu/staffinfo/pdf/scanlon_vadosezj.pdf
- Fact Sheet on Evapotranspiration Cover Systems for Waste Containment, US EPA, http://www.epa.gov/tio/download/remed/epa542f11001.pdf

Opinions

Our modeling and monitoring of conditions in the Permian Basin support the general findings of the referenced publications and the testimony of experts at the Pit Rule hearings. We conclude:

1. The moisture flux (water drainage) is essentially zero beneath a 4-foot thick, sloped monolithic soil cover constructed in a manner consistent with the Pit Rule with a loamy-sand topsoil overlaying a coarser-grained caliche and/or sand layer.
2. At a 4-foot depth, an upward moisture flux beneath a cover composed of heterogeneous earth material is also essentially zero
3. Given the lack of any significant moisture flux at a depth of 4-feet, horizontal migration of moisture from adjacent soils/subsoil into buried waste is also zero
4. Under these conditions, a Geomembrane liner is not necessary

Maximum Seepage Case Scenario – Flux/ Solute Transport Up and Down

This scenario assumes minimal compliance with the Pit Rule and certain site-specific conditions:

1. Less than one-foot of topsoil (or "suitable material") in certain areas overlying the pit footprint.
2. The "topsoil" is dune sand, which is not uncommon in the Permian Basin and not materially finer-grained than the underlying soil cover.

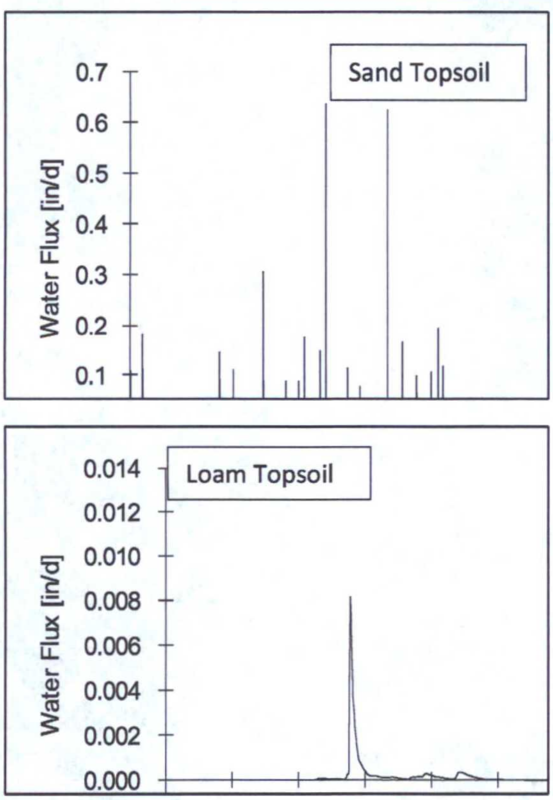
3. Beneath the dune sand topsoil is at 2-3 feet of clean, dune sand – less than the minimum thickness required by the Pit Rule can occur due to movement of dunes prior to stabilization by vegetation.
4. The graded ground surface over the stabilized material approximates low dunes of the area and does not prevent localized ponding of water or minor wind erosion of the cover material. Thus, over time, the manufactured low dunes of the soil cover may become more pronounced by the formation of small "blow outs" that collect water
5. A plant cover of at least seventy percent (70%) of pre-disturbance levels may cover the area of the reclaimed pit site. However, the pre-disturbance vegetation in the dune field was low and thus vegetation may not cover much of the manufactured dune field over the stabilized pit solids.

Research

Our modeling of unsaturated flow in the Permian Basin provides results that are consistent with our observations: beneath a relatively homogeneous sand layer (dune sand) precipitation will migrate below 4-feet. Beneath sandy areas where stormwater can accumulate, such as in dune blow out areas, the moisture flux will be greatest.

Not only are these observations relatively obvious, they are supported by peer reviewed research. A field study of deep drainage (recharge) beneath dune sand is available at the web site http://wrri.nmsu.edu/publish/techrpt/tr177/tr177.pdf. Numerous more recent peer reviewed paper are readily available on the web that provide estimates of recharge through sand dunes.

The fluid mechanics of unsaturated flow through sand in the Permian Basin can be illustrated by AMIGO simulations (see http://www.americanpetroleuminstitute.com/environment-health-and-safety/clean-water/surface-water-quality/api-amigo-online-decision-support-tool). The AMIGO simulation to the left shows the moisture flux at 10-feet below ground surface for a medium sand topsoil and medium sand underlying the soil. This simulation predicts relatively large pulses of recharge occurring at 18, 27, 36, and at 60 plus years. These recharge pulses are responses to large rainfall events over a short period that typically occur during the El Nino cycles. The simulation demonstrates the obvious, migration of moisture from the surface to the Geomembrane liner occurs. The simulated moisture flux ranges from less than 0.1 inches/day to more than 0.6 inches per day. Pulses of recharge occur with almost yearly regularity. The AMIGO model employs daily weather data from Pearl, NM (about 10 miles west of Hobbs)



The second AMIGO simulation to the left assumes loam topsoil overlying medium sand and caliche subsoil. The moisture flux at 10 feet beneath the surface is less than 10 percent of the simulation using a medium sand topsoil and measurable recharge events occur only twice over the 80 year period. These small and infrequent recharge events are a principal reason that many experts, including Hicks Consultants, believe that a Geomembrane cover is not required in in the Permian Basin where a sandy-loam topsoil overlies heterogeneous caliche/sand fill layer.

Because moisture flux will occur under dune sand conditions (relatively homogeneous media), the long-term degradation of the geomembrane cover will effect when/how/if chloride in the stabilized cuttings migrates up or down. Also, lateral migration from the edges of the liner to the stabilized waste may or may not pose an environmental threat.

With respect to lateral migration, non-vertical flow has been documented experimentally in heterogeneous media and would be expected to also exist in the field. However, as stated in the previously-referenced USGS summary of unsaturated zone processes: "[Unsaturated] flow is often assumed to be predominantly vertical because

i. with a continuous air phase in the pores, buoyancy does not counteract gravity as it does in the saturated zone, and
ii. whatever the effect of other forces, gravity acts vertically."

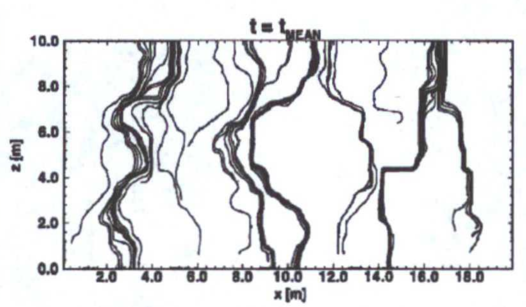
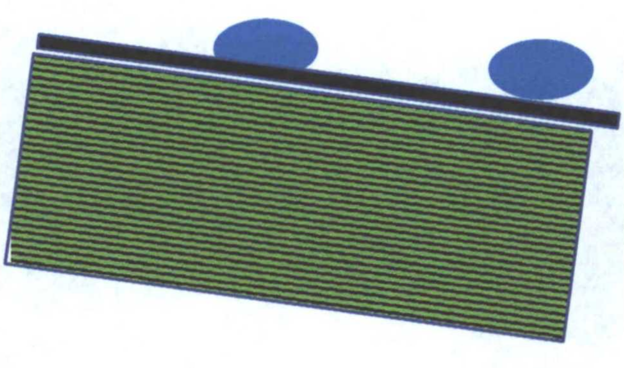


Figure 17. Particle tracks for case U1 ($Q_{inf}/Q_{inf}^{sat} = 10^{-5}$).

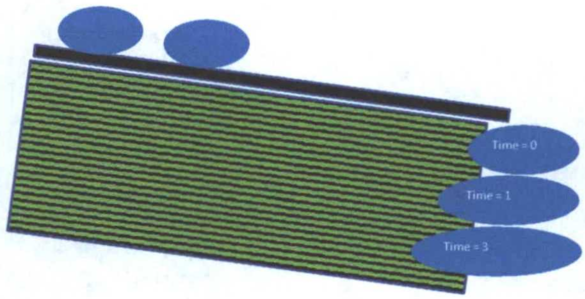
This same USGS publication also presents several examples of non-vertical flow, some of which may be expected in the Permian Basin.

The magnitude of horizontal flow paths is discussed in the paper http://onlinelibrary.wiley.com/doi/10.1029/97WR01209/pdf. The adjacent figure (17) from that paper shows that numerical predictions of solute flow paths over the 10 meter thick column (heterogeneous) suggest that flow can move as much as 3 meters horizontally over the 10 meter vertical column. This magnitude of horizontal flow would not occur under the more homogeneous conditions of fill (or berms) comprised of dune sand.

Non-vertical unsaturated flow will occur within heterogeneous porous media, such as residual drilling solids stabilized with dune sand and broken caliche fill that forms the berms between the cells of many reserve pits. The geomembrane cover also creates significant heterogeneity (an impermeable sloping layer) that will cause increased moisture content and lateral movement of moisture along the sloped surface. At the boundary between the overlying dune sand, the geomembrane cap, the underlying stabilized drilling solids and the adjacent material (e.g. dune sand or a natural clay/caliche layer), moisture will move vertically with some dispersion (horizontal component of movement). The figures below present a realistic example that describes this relationship.



About 3-5 years after pit closure, the first pulse of moisture reaches the liner. After the next pulse of infiltration, about 7-15 years after closure, the moisture content of the dune sand immediately above the liner is sufficiently large that the moisture is expected to migrate down slope of the liner to the edge.



In the next figure, Time = 0 is about 15-20 years after closure. At Time=0, moisture that collected at the edge of the geomembrane cap begins to intrude into the heterogeneous stabilized cuttings, moving vertically and horizontally at a <u>maximum</u> expected ratio of 3 feet vertical to 1 foot horizontal. Time = 1 is about 20-25 years after closure and Time = 2 could be 27-32 years after closure, depending upon the frequency of moisture pulses moving through the dune sand.

As moisture moves downward and into the stabilized solids in response to gravity, the horizontal migration into the stabilized solids could be 3V:1H or less. At a typical closed reserve pit, the maximum expected intrusion of moisture into the stabilized cuttings from the edge of the geomembrane cover is about 1.5 feet if:

- maximum thickness of stabilized cuttings in the pit is 9 feet (a reasonable estimate)
- slope of the liner is 4.5H:1V (reasonable estimate)
- downslope length of the slope is 9-18 feet (reasonable estimate)
- ratio of vertical to horizontal moisture movement is 3V:1H
- 5 feet of stabilized cuttings lie at an elevation lower than the edge of the geomembrane cap.

In addition to intrusion of moisture into the stabilized solids from the edges of the liner, as tears and holes occur in the liner, intrusion of moisture will also occur. According to the publication <u>http://www.geosynthetic-institute.org/papers/paper6.pdf</u>, Table 2 (below) presents the lifetime predictions of unexposed (e.g. buried) HDPE. For reference, this same paper estimates the lifetimes of exposed HDPE and LLDPE as 36 years. Various publications suggest that the lifetime of unexposed LLDPE would be slightly less than buried HDPE.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years) Standard OIT	High Press. OIT	Average OIT	Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Assuming a soil temperature at 4-feet below grade in the Permian Basin is 20°C (about 70°F), the Table suggests that degradation of LLDPE under standard pressure (expected for a geomembrane cover buried at only 4-feet) would begin sometime before 200 years as oxidation of the liner reduces the strength (Stage A is when Oxidative Induction Time, OIT, begins). This report suggests that actual degradation (loss of integrity) of an LLDPE liner would occur less than 30 years after the onset of oxidation (Stage B). The table suggests that for LLDPE less than 208 years are required from the time of initial degradation to a loss of 50% of LLDPE liner integrity (the half-life, Stage C). However, under field conditions where 100% of the seams may not be perfectly welded according to standards, some stress cracking of the liner may occur, creating localized loss of integrity at these tears earlier than shown in the Table (see http://www.geosynthetica.net/Uploads/IDPigsUKpaper.pdf).

As holes and cracks appear in the geomembrane cap, intrusion of moisture into the stabilized drilling solids will occur. Intrusion of moisture into the drilling solids, from cracks or from the edges of the cap, will cause the downward vertical migration of soluble constituents, such as chloride. The dominant downward migration may have a horizontal component of as much as 1H:3V in heterogeneous earth material.

Opinion

1. Upward wicking of moisture through relatively homogeneous dune sand will not occur at depths greater than 4-feet
2. About 15-20 year after closure, pulses of moisture will intrude about 1-2 feet into the stabilized solids from the edges of the geomembrane cap. This intrusion will cause the downward migration of soluble constituents, such as chloride, from about 5% of the buried waste [(1.5/18)*(5/9) = 5%].
3. The mass of soluble constituents within this 5% of the buried solids will migrate downward over decades while the majority of the soluble material mass remains relatively immobile beneath the geomembrane cap.
4. Some stress cracks and tears in the geomembrane cap will occur before year 200 (after closure), allowing the intrusion of moisture and downward migration of soluble constituents. These stress cracks will allow a minor amount of moisture intrusion and a minor mass of soluble constituents to migrate downward from the stabilized waste. A reasonable estimate of the mass removed before year 200 by this process is 5%.
5. Beginning before year 200 and continuing for more than a century, the LLDPE geomembrane cover will degrade by 50%, rendering the cover ineffective. Intrusion of moisture through the failed portions of the cover as they occur will migrate that portion of soluble constituents in the buried solids downwards. In this manner, the remaining 90% of the mass of soluble constituents are migrated downwards as the liner degrades at a rate of less than 1% of the mass per year.
6. LLDPE that has been exposed to UV degradation and stress (e.g. high-quality liner reclaimed from pits) would have a significantly shorter total lifespan. This is documented in publications and obvious by observation in the field.
7. The best geomembrane cover for the on-site burial of drilling solids would create the longest time period of liner degradation. This liner will result in minimal moisture intrusion per year (i.e. the smallest mass flux per year of soluble constituents). Such a cover could be
    a. New, welded LLDPE comprising 50% of the cover, which would begin to lose integrity before year 200 after closure
    b. Reclaimed pit liner comprising 50% of the cover, which would begin to lose integrity significantly earlier, probably before year 100 after closure.

This design could add almost an additional century (in this example) to the time span that liner degradation occurs within.

Contractor Instructions for Temporary Pit In-Place Closure

General Protocols and Procedures

- Before drilling pit closure begins all free liquids from the pit will be recycled or disposed in a manner consistent with OCD Rules.
- Residual drilling fluids will be removed from the pit within 60 days of release of the last drilling rig associated with the relevant pit permit.
- Water derived from the well stimulation program (flow-back or unused fresh water) *may* discharge into the pit if the water could be re-used for E&P operations
- Well stimulation water *may* discharge into a drainage system in the pit to flow through the solids or onto the solids in the pit, reducing the levels of certain constituents by rinsing or transferring oxygen or other amendments into the solids.
- A pump *may* be utilized remove water from the drainage system to a tank or to another cell of the pit (ie, the brine or fluids cell) of the temporary pit; thereby further rinsing the residual solids in the pit.
- The residual drilling mud and cuttings will be stabilized to a capacity sufficient to support the 4-foot thick soil cover.
- The residual pit solids will be mixed at a ratio not to exceed 1-part pit solids to 3-parts dry earth material (e.g. subsoil) prior to any sampling for compliance with the Rule.

Protocols and Procedures for Earthwork

Stabilization of the residual cuttings and mud is accomplished by mixing dry earth material within the temporary pit footprint. Requirements of the operator or qualified contractor are as follows:

A. The pit liner will be cut at the solids level and removed. At this time, an operator's representative will be present to observe the nature of the material beneath the liner.
B. The solids will be mixed with clean fill from the sides and bottom of the pit footprint to absorb moisture for initial stabilization.
C. After initial stabilization, the solids may be allowed to dry for several days prior to continuing with closure.
D. Additional dry fill will be added to the pit solids as necessary to allow grading of the stabilized solids to allow placement of the Geomembrane cover.
E. The upper surface of the stabilized cuttings will be:
   a. Sloped in a manner to prevent infiltration of water and so that infiltrated water does not collect on the overlying geomembrane cover after the upper soil cover has been placed. If feasible, the surface of the stabilized solids will be sloped at about 3-5H:1V
   b. At least 4-feet below the natural elevation of the area as measured and documented by the operator's representative.
   c. Pass the paint filter liquids test according to the observations of the operator's representative.

After stabilization the operator or qualified contractor will:

1. Place a geomembrane cover over the sloping surface of the stabilized waste material, covering all exposed areas of stabilized solids plus areas outside of the stabilized cuttings as directed by the operator's representative.
2. Use new geomembrane cover made of 20-mil string reinforced LLDPE liner with welded seams
3. Place the **Soil Cover** over the sloping, stabilized material and liner. The soil cover includes:
   a. At least 3-feet of compacted, uncontaminated, non-waste containing earthen fill with chloride concentrations less than 600 mg/kg as analyzed by EPA Method 300.0.
   b. Either the background thickness of topsoil or one foot of suitable material to establish vegetation at the site, whichever is greater, over the 3-foot earth material.
4. Contour the cover to:
   a. Blend with the surrounding topography
   b. Prevent erosion of the cover and
   c. Prevent ponding over the cover.

Reclamation and Re-vegetation Plan

In addition to the area of the in-place burial, the contractor will reclaim the surface impacted by the temporary pit, including access roads associated with the pit, to a safe and stable condition that blends with the surrounding undisturbed area.

For all areas disturbed by the closure process that will not be used for production operations or future drilling, the operator will:

I. Replace the topsoil and subsoil to their original relative positions
II. Grade the surface so as to achieve erosion control, long-term stability. This should include seeding/furrowing along the elevation contour.
III. Reclamation should preserve storm water drainage patterns
IV. Reseed all reclaimed areas in the first favorable growing season following closure

Re-vegetation and reclamation plans imposed by the surface owner will be outlined in communications with the OCD.

When the site meets the surface owner's requirements (e.g. seed mix) or exhibit a uniform vegetative cover that reflects a life-form ratio of plus or minus fifty percent (50%) of pre-disturbance levels and a total percent plant cover of at least seventy percent (70%) of pre-disturbance levels, excluding noxious weeds, a final report will be submitted to the OCD.