TULLY VALLEY MUDBOIL MITIGATION ALTERNATIVES ANALYSIS

Selection Criteria & Potential Actions

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Abstract: The Onondaga Creek corridor in Onondaga County, NY has been impacted by halite mining, channelization, overdevelopment, and numerous municipal and industrial point and non-point pollution sources over the last 150 years, resulting in severe degradation of the creek, its tributaries, riparian zones, and wetlands. The source of the pervasive sedimentation is from a hydrogeological phenomenon known as mudboils (Fig. 1). An alternatives analysis was performed to present an option or suite of options that could undergo a feasibility study (FS). The FS would determine if an engineering design for capturing and remediating the effects of mudboil discharge sediments on downstream conditions could be implemented in the Upper Onondaga Creek watershed as a short-term measure while a long-term solution addressing the causation of mudboils is being sought. The results of that analysis and the recommendations for FS are presented herein.

August 6, 2021

Figure 1. Aerial view of current active and known historic Tully Valley Mudboil Area (Onondaga County, NY). The mudboil area is outlined in orange.

Preliminary Selection Criteria Definitions: The Design Team (DT) established a one or two *keyword-term* to describe selection criteria (depicted below by Roman numeral heading). Selection criteria are intended to serve as separate and distinctive (not overlapping) categories; each representative of a matrix consisting of multiple factors, parameters, or measurements. Selection criteria will be used in evaluating *potential actions* that could remediate the effects of *mudboil discharge* on downstream conditions. Next the DT constructed an applicable *question* to which the answer identified an associated *index* that could be measured across a quantitative scale or range[1]. Subsequently, the resultant *answer* to the question was representative of the combined expression of the matrix of factors, parameters, or measurements reflected in the keyword term.

Goal: is to capture materials sourced to the mudboils, and to have downstream water quality equal to upstream conditions.

I. Efficacy/Performance: The first and most important selection criteria is the efficiency at which the potential action removes mudboil sourced sediments from the system.

A. Reduce mudboil sediment[2] load to Onondaga Creek

1. Turbidity[3] < 5 nephelometric units (NTUs)[4] [5]
2. Onondaga Environmental Institute (OEI) interpretative scale[6]

What is the Potential Action's ability to reduce sediment load? And improve water quality?

High: Delta between upstream and downstream (turbidity < 5 NTUs)
Med: Delta between upstream and downstream (turbidity 5 to 50 NTUs)
Low: Delta between upstream and downstream (turbidity > 50 NTUs)

Note: For the most part, > 150 NTU delta between upstream and downstream turbidity would be unacceptable.

B. Reduce mudboil salt[7] (dissolved solids) load to Onondaga Creek

1. Salinity < 3 ppt

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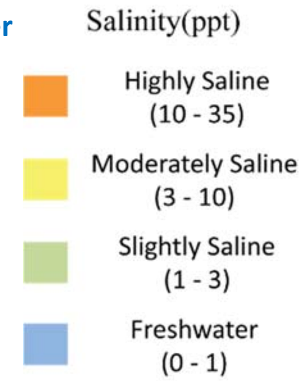
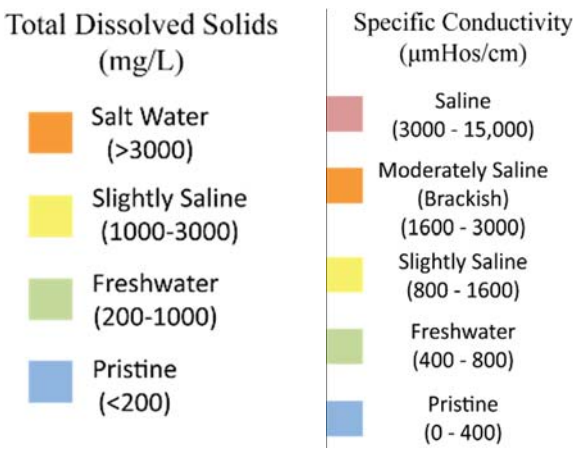
[1] Scales were ordered and demarcated along a continuum according to preferences of high, medium or low.
[2] Mass loading is most important.
[3] Turbidity is measured in nephelometric turbidity units (NTUs). The instrument used for measuring it is called nephelometer or turbidimeter, which measures the intensity of white light scattered at 90 degrees as a beam of light passes through a water sample.
[4] New York State Law Part 703: *Surface Water and Groundwater Quality Standards and Groundwater Effluent Limitations*; Part §703.2 Narrative water quality standards for the following classes of waters (AA, A, B, C, D, SA, SB, SC, I, SD, A-Special, GA, GSA, GSB): No increase that will cause a substantial visible contrast to natural conditions. Part §703.3 Water quality standards for pH, dissolved oxygen, dissolved solids, odor, color and turbidity: Shall not exceed 5 nephelometric units.
[5] NYSDEC water quality standard for runoff from a construction site could serve as an appropriate "low" or minimum threshold for efficacy.
[6] Based on literature review and approval of the microbial trackdown study working group 2009.
[7] The salt content of water is determined according to two main methods: Total Dissolved Salts (or Solids) (TDS) and Electrical Conductivity. TDS is measured by evaporating a known volume of water to dryness, then weighing the remaining solid residue.

What is the Potential Action's ability to reduce salt load? And improve water quality?

High: Delta between upstream and downstream salinity < 3 ppt
Med: Delta between upstream and downstream salinity 3 to 10 ppt
Low: Delta between upstream and downstream salinity > 10 ppt



Note: Total dissolved solids and specific conductivity can serve as surrogate measurements for salinity.



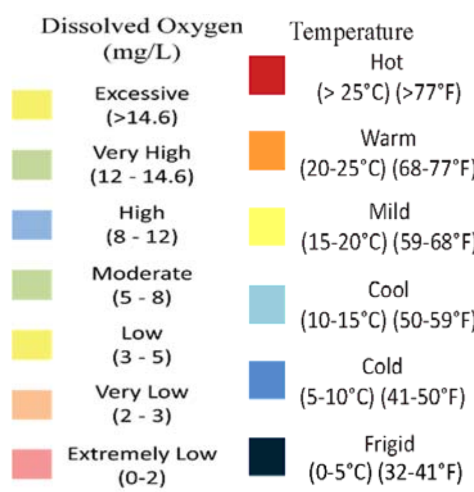
II. Environmental Compatibility/Eco-sensitivity: Natural landscapes & processes (Ecosystem structures & functions) vs Human Interventions (construction, industrial & mechanical operations & associated externalities, i.e. chemical, odor, noise, traffic & visual pollution)

A. Water quality parameters

1. Dissolved oxygen > 8 mg/L[8]/ > 90% saturation
2. Temperature < 20°C[9]

B. Suitability to support trout

1. NYS classification scheme
2. Presence-absence/reproduction/habitat



Does the Potential Action blend into the natural/agricultural setting?

High: integrates well into the landscape
Med: moderately integrates into landscape;

[8] Part §703.3 Water quality standards for pH, dissolved oxygen, dissolved solids, odor, color and turbidity: For trout spawning waters (TS) the DO concentration shall not be less than 7.0 mg/L from other than natural conditions. For trout waters (T), the minimum daily average shall not be less than 6.0 mg/L, and at no time shall the concentration be less than 5.0 mg/L.

[9] Temperature and dissolved oxygen are intrinsically related and are strongly correlated, as DO levels are temperature dependent.

Project includes some hard, structural elements

Low: does not integrate into the landscape;
Project includes many hard, structural elements

III. Administrative Implementability: (Degree of Difficulty is determined by many factors as measured by time)

A. Land ownership

B. Regulatory/jurisdictional issues

1. New York State Department of Environmental Conservation (NYSDEC)- US Army Corps of Engineers (USACE) wetland and stream disturbance permits
2. 303(d) list (Total Maximum Daily Load [TMDL])
3. Federal Emergency Management Agency (FEMA) flood maps
4. Municipal zoning
5. State Environmental Quality Review (SEQR)

C. Project ownership

Will the administrative implementation of the Potential Action be expedient?

High: Small amount of private land with fluid permit process (< 6 months)

Med: Mix of private & corporate land (Honeywell properties) with moderate permit process (6 to 18 months)

Low: Majority of private land with lengthy permit process (> 18 months)

IV. Technical Implementability: (Degree of Difficulty as also expressed by time and via areal size of project footprint/land consumed)

A. Proven technologies (design guidance)

B. Complexity and uncertainty of implementing action given the nature of the technology and the environment (High performance/hydrology)

V. Permanence/Longevity:

A. Life expectancy/Design life: ability to maintain performance/without loss of effectiveness or degradation of function

B. Maintenance requirements (schedule)

What is the projected design life of the Potential Action given proper design maintenance?

High: > 25 years

Med: 10 to 25 years

Low: < 10 years

VI. Adaptability: (Adaptive management i.e. is the Action either inherently capable of effectiveness under changed conditions or through reasonably feasible modifications following initial construction)

A. Ability to adjust/modify strategy/remedies

B. Changing field conditions:

1. New rogue mudboil, 2. Subsidence, 3. Shifting streambed, 4. Landslides

C. Reversibility (ability to remove or reverse the remedy should it no longer be needed or adverse effects occur)

How adaptable is the Potential Action to changing field conditions?

High: Very adaptable
Med: Moderately adaptable
Low: Relatively adaptable

VII. Implementation Costs: Total expenses associated with planning, designing, permitting and constructing the potential action.

Will the implementation costs of the Potential Action be inexpensive?

High: < $500,000
Med: $500,000 to $1,000,000
Low: > $1,000,000

VIII. Maintenance Costs: Total expenses associated with operation and maintenance of the potential action on an annual basis[10].

Will the annual maintenance costs of the Potential Action be inexpensive?

High: < $50,000
Med: $50,000 to $100,000
Low: > $100,000

IX. Social factors/benefits:

A. Cultural significance/importance

B. Safety

C. Recreation

D. Public/stakeholder acceptance

[10] Maintenance costs to be reviewed under the FS include the net present value (NPV) of total operation & maintenance (O&M) costs and maintenance cost efficiency. Potential funding sources (i.e., offset costs, system value-NRD type losses/versus costs of other remedies) will also be a consideration.

A. Description & Rating of Potential Actions:

A surface barrier to prevent source water from infiltrating ground water was also eliminated from further consideration pending results from the US Geological Survey (USGS) time-domain electromagnetics (TEM) Tully Valley ground water model. The Tully Valley TEM ground water model is needed to better evaluate this potential remedy. Likely sources of hydraulic pressure to ground water influencing mudboil activity includes surficial recharge locations along the Valley walls and tributaries to the Onondaga Creek mainstem. However, the increasing saline character of mudboil vent waters suggests a deep aquifer dynamic potentially influenced by former solution mining activities, subsequent rock fracturing, land subsidence, and instability that could be more important than surficial hydraulics. Any long-term solution is dependent upon findings of the USGS TEM groundwater model and a deeper understanding of the subsurface geology and hydrology (Figure 2). Consequently, remedial efforts involving subsurface potential actions and source water controls were not considered. Still, due to the highly unstable nature of the Tully Valley land surface and attendant mudboil activity, any selected potential action at the surface also requires an understanding of the innate risks and uncertainty associated with the proposed remedy and selected site. The following section summarizes the uncertainty of future mudboil remediation as exemplified in the past.

Scientific Uncertainty and Past Experience

Causal relationships in natural systems are often difficult to determine. Multivariate factors and data scarcity often lead to difficulty in scientifically isolating and attributing a singular effect to a particular cause or set of causes. Human interventions can often influence natural system dynamics such that resultant repetitive consequences can be predicted for future actions based on past experiences. Often, however, the nature or degree of other consequences may be unforeseen or unanticipated due to scientific uncertainty.

Mudboil phenomena and associated land subsidence occur under complex and difficult to ascertain sets of natural conditions, the scientific basis for the occurrence of mudboil activity is reasonably well understood. Certain and anecdotal evidence exists to suggest human intervention has had a major role in promoting and/or influencing mudboil activity. Figure 3 depicts a chronology of drilling and solution mining operations in the Tully Valley along with documented historic mudboil activity, land subsidence, landslide occurrence and saline water quality impacts. At a minimum, deep well installation and the practice of solution mining has exacerbated land subsidence and mudboil activity (reference).

Despite what is understood about the phenomenon, however, predictions regarding the location the intensity and duration of future mudboil activity is difficult and involve a high level of uncertainty.

A major concern with selecting potential actions for future implementation is understanding the likelihood of further post-construction mudboil activity. What is the risk of the potential action? In other words, will the potential action designed to control mudboils cause or lead to further mudboils? At this stage of the evaluation and for the purposes of this project, the level of uncertainty or risk associated with each conceptual potential action cannot be identified. Yet, a retrospective assessment of the historical record can be used prospectively to render an expectation of the inherent risk of implementing a potential action. Figure 4 depicts a chronology of past research and mudboil remedial actions performed by the USGS. Again, this historical record can provide “lessons learned” to help guide recommendations towards selecting potential actions to mitigate mudboil activity. Presented below is a summary of past remedial measures, subsequent mudboil activity, and uncertainty with respect to the permanence of future actions.

Remedial Measure 1: (Tributary Relocation):

Summary: In 1992, an unnamed tributary flowing through the main depression area (MDA) and draining the sub-basin to the west of the MDA was relocated. The relocation was performed to reduce the volume of water flowing through the MDA and picking up sediments released by mudboil activity and carried to Onondaga Creek.

Subsequent Activity: As of 2018, over 25 years later, there is evidence that sheet flow and to some limited extent, former drainage patterns may have re-established and flows through the MDA are greater than that of the post-remedial action. Although Onondaga County DOT and the Town of Lafayette Highway Department maintain culverts under Tully Farms Road and the drainage sluices along the road banks, very little to no maintenance has been performed in preserving the drainage patterns established in the 1992 tributary relocation.

Lessons learned: Topography and natural forces tend to return water drainage flows to pretreatment or similar patterns that offer the least resistance. Ongoing maintenance is required to retain constructed and altered surficial drainage patterns.

Remedial Measure 2: (Depressurizing Wells):

Summary: In 1996, thirteen ground water wells were drilled; one boring was not lined, and one dozen depressurizing wells were installed around the mudboil corridor, MDA, and Onondaga Creek. Depressurizing wells were installed to relieve hydraulic pressure causing ground water to upwell; thereby, carrying fine sediments to the ground surface in the form of mudboils. The release of clean water via depressurizing wells showed a localized relief of hydraulic pressure of about 2.5 ft of hydraulic head.

Subsequent Activity: Depressurizing wells varied individually in discharge rate (<5 gal/min to >100 gal/min) seasonally depending on precipitation and recharge conditions. Depressurizing wells set in very fine to fine, silty sand discharged clear water at average rates of 2 to <10 gal/min. Those depressurizing wells set in medium, silty sand discharged clear water at average rates of 10 to 30 gal/min. Discharge rates varied seasonally from 30 to 50% less and from 30 to 50% greater than the average flow rate during dry and wet periods, respectively. Overtime all discharge rates slowed and stopped in some wells due to the upward translocation of fines resulting in plugging of the well screens. In 1995, five depressurizing wells were redeveloped; however, subsequent discharge rates improved in only one well, remained static in two wells and declined in two wells. As discharge rates declined from 1995 to 2012, specific conductivity increased accordingly. This trend is consistent with the evolution of mudboils, as discharge waters transition over time from fresh water at initial break out to saline character over time (Waller 1977). The increasing salinity in mudboil and depressurizing well discharges is due to a reduction in the quantity and quality of waters drawn from the upper freshwater aquifer concomitant with an increase in waters drawn from the lower brackish aquifer (Kappel 2014).

In 1997, mudboil activity commenced in an area near the "Creekside" depressurizing well (OD464) (finished in medium gravel); the depressurizing well with the greatest discharge rate (>50 gal/min). This area of mudboil activity was denoted as the Rogue mudboil area (RMA). From 1997 to 2010, rogue mudboil activity increased, subsidence expanded, and a number of mitigating measures were implemented by USGS to reduce sediment loads to Onondaga Creek. In 1997 after aborting an attempt to service the Creekside depressurizing well due to ground surface instability, a second depressurizing well was installed on the farm field side of the RMA. This "Fieldside" depressurizing well (OD471) (finished in coarse gravel) also discharged copious amounts of water (>100 gal/min) for several years. In 2006, the Fieldside depressurizing well began discharging sediment laden water and a mudboil developed at the base of the well in 2007. Subsidence from the western edge of the RMA claimed the Fieldside depressurizing well shortly thereafter. In March of 2009, the eastern dike subsided and the RMA commenced to discharge sediments directly into Onondaga Creek. A mudboil subsequently developed at the base of the Creekside depressurizing well. The dike was reinforced and sediment laden waters from the Creekside depressurizing well was redirected into the containment area. However, one year later the dike and Creekside depressurizing well slowly subsided into the expanding RMA.

Lessons learned: Historic areas of mudboil activity are unstable. Kappel 2014 cites two likely causes of development of the RMA:

1. Depressurizing wells may have reduced artesian pressure leading to land-surface subsidence, ring fracture development, and lateral expansion of the RMA.
2. Effective capture of sediments in the MDA over a 12-year period created a cap layer, locally increased artesian pressure, and the nearby RMA provided relief for new mudboil vents.

Kappel 2014 describes the rogue mudboil activity and the likely relationship with the presence of depressurizing wells (pgs. 20-22). Nevertheless, drilling, excavation, and subsurface disturbances are to be avoided in areas prone to mudboil activity.

Generalized Potential Actions

The DT formulated a total of five generalized potential actions (Figure 5). The generalized potential actions were intended to be conceptual remedies with minimal overlap amongst the strategies used to control mudboils. Each generalized potential action was initially considered theoretically capable of achieving the top-level project objective of reducing sedimentation and salinity to Onondaga Creek to the extent that water quality downstream of the mudboils is equivalent to that of upstream. The generalized technological potential actions are:

1. Offline settling of mudboil sediments
2. At-source settling of mudboil sediments at areas of mudboil activity
3. Physical separation of Onondaga Creek from Mudboils
4. At-source clean water flow (Q) diversion
5. Inline Downstream Settling

The following outline describes the technical work elements associated with each of the five potential actions.

A. Potential Actions:

1. Offline Settling (e.g., Basins at Nichols Rd [Hard])

A. Divert creek into a parallel system of settling basins
B. Diversion and basins accommodate base flow
C. High Q and storm events by pass the system and remain in the creek channel
D. System is designed against flood protection
E. System is maintained by parallel ponds: one pond is drained, sediments are removed and disposed while other pond is in service
F. Sediments are disposed back into the MDA
G. Water leaves the settling pond and is polished in a natural wetland prior to discharge back into the creek (see Potential Action III).

Action 1b: Develop a series of industrial ponds in parallel (Hard)

2. At-Source Settling (e.g., Basin at Rogue MB [Soft])

A. Demonstration project
B. Dam of variable size (could be inflatable)
C. Impounded water causes settling at the source
D. Limit/minimize runoff into Rogue area (see Potential Action 6)

3. Onondaga Creek Relocation Around Mudboils

A. Start the relocation as far upstream as to avoid potential mudboil activity (need maps of Honeywell properties/solution mining wells and fractures) (LiDAR data – map canal)
B. Rejoin existing creek as far downstream as to avoid potential mudboil activity (greatest linear distance possible South to North)
C. Move as far to the west/east as to avoid mudboil activity
D. Combine with other potential actions to settle mudboil activity on-site/utilizing former (currently existing) creek channel

4. At-source water flow (Q) diversion from MDA

A. Actual MDA Q
   1. Similar to directional drill project
   2. Could be located as identified in TVGT report
B. Q into MDA
   1. Redirect flow that is entering MDA/analogous to 1993 tributary relocation to the south
   2. Reduce the size of drainage basin (subwatershed entering MDA)
   3. Reduce volume of water flowing through active RMA

5. **Inline Downstream Settling (Downstream of Mudboil Activity)**
    A. Create settling impoundment/reservoir
    B. Reservoir could cover active mudboil areas
        1. Could cover rogue
        2. Could cover MDA
        3. Could cover both
    C. Could be a series of dams/reservoirs capturing Onondaga Creek (EMM's conceptual drawings from 9/14/18: #s 1 & 2)
    D. This option becomes Potential Action II if Potential Action V is implemented and Onondaga Creek is relocated
    E. Reservoirs would warm the water
    F. Preference would be to have settling occur off-line

Each of the "Five potential actions" is described below, followed by a discussion of its ranking according to the selection criteria. As noted previously, **"I efficacy – potential effectiveness" is** the top selection criteria based on the project goal of reducing sedimentation and salinity to achieve water quality downstream of known mudboil activity equivalent to that of upstream. In addition to the "efficacy - potential effectiveness" criteria a discussion of how the action scores relative to six secondary selection criteria of**:**

II. environmental compatibility,
III. administrative implementability,
IV. technical implementability,
V. permanence,
VI. adaptability, and
VII/VIII. cost[11].

Each potential action was given a rating of "high," "medium," or "low" representing its favorability with respect to each selection criteria, color coded in the summary tables for each potential action as follows:

● = Highly favorable
● = Moderately favorable
● = Less favorable

[11] For the sake of this exercise, costs were treated as a single criteria, and Social Factors were not included in the evaluation.

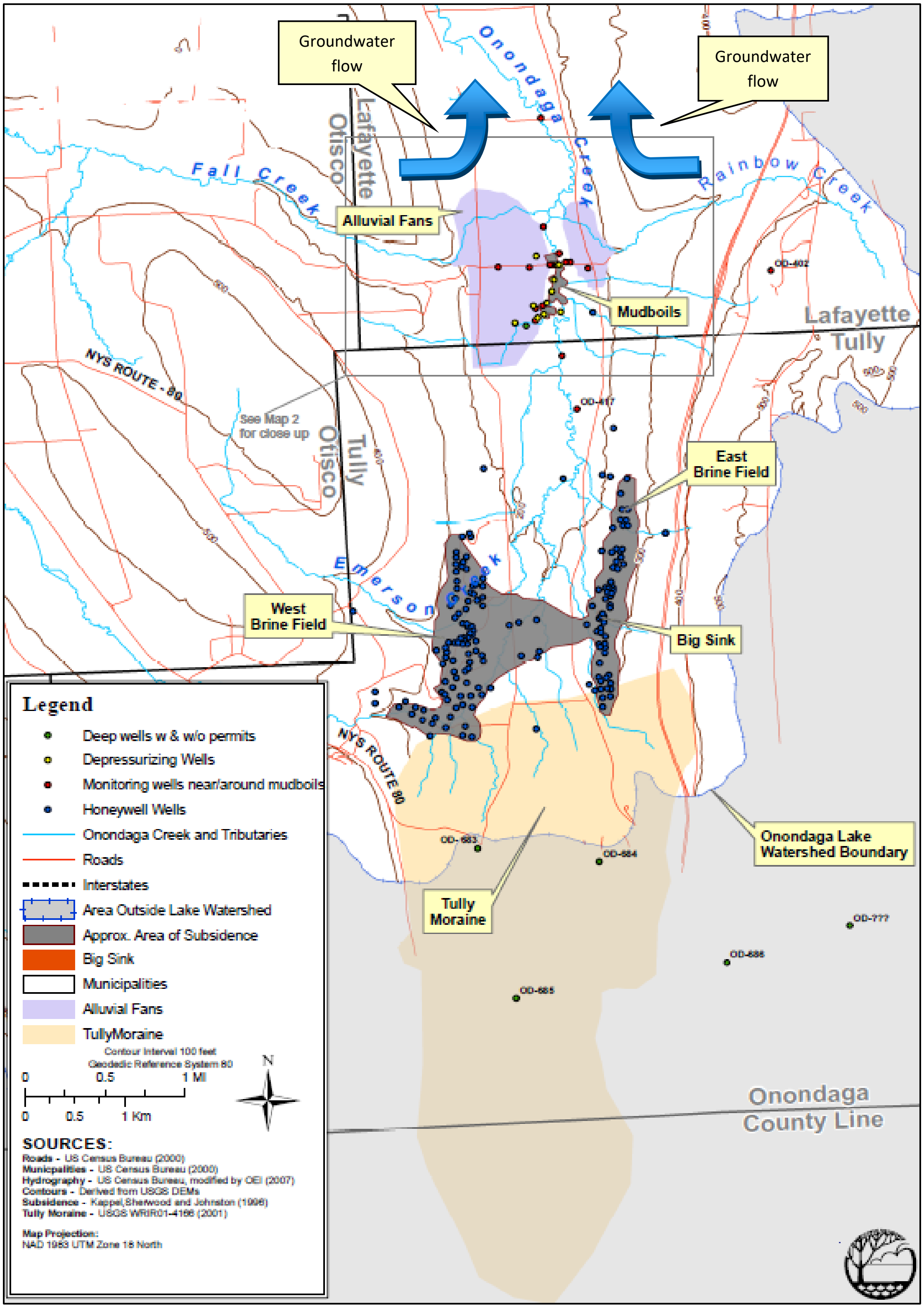


Figure 2. Wells and activities in the Tully Valley (Onondaga County, NY) associated with the historical solution mining industry. The direction of groundwater flow from the valley walls into Onondaga Creek is denoted by the arrows.

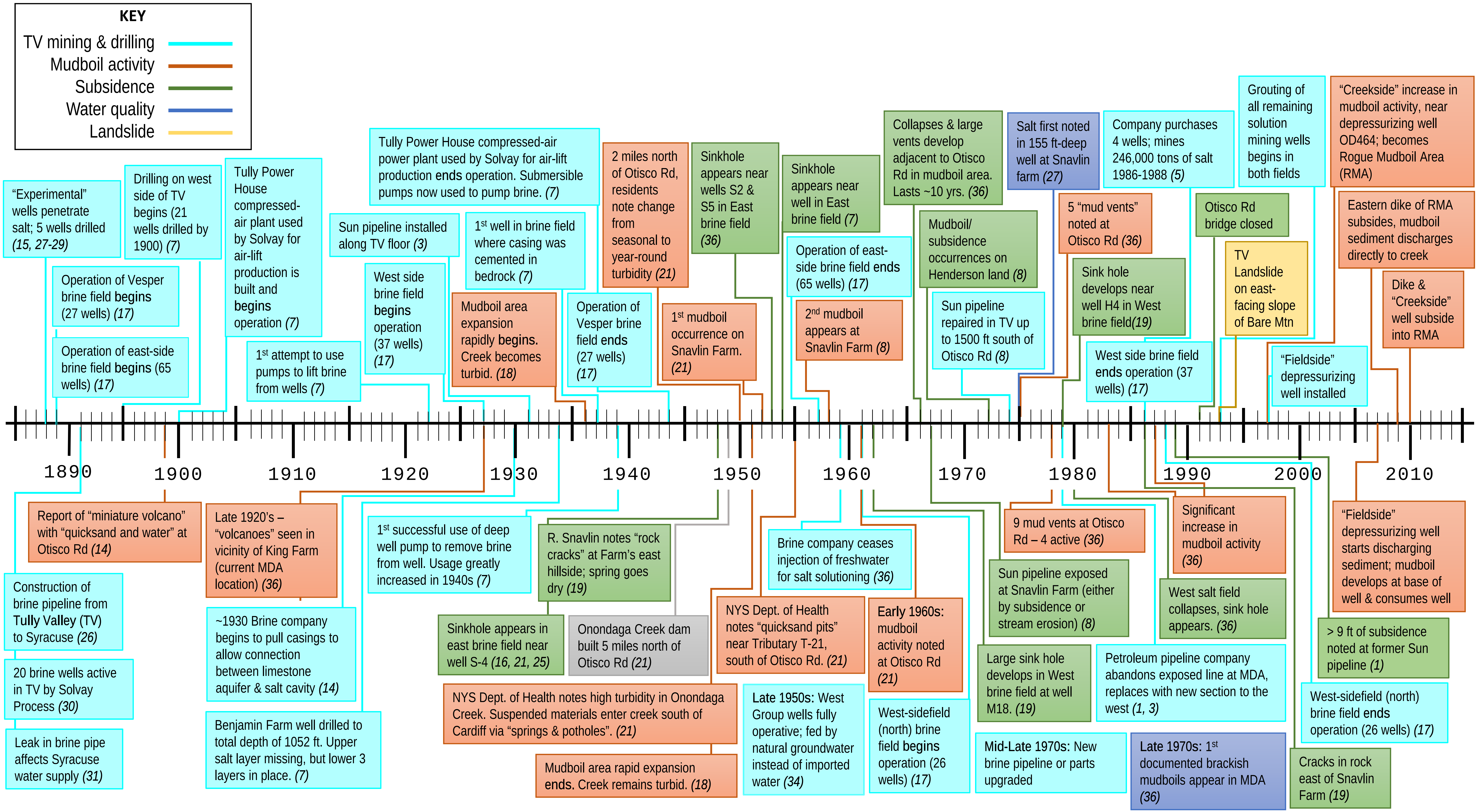


Figure 3. Tully Valley Mudboils historical timeline (1885-2010). MDA= Mudboil Depression Area; TV = Tully Valley.Reference numbers *(#)* correspond to those as referenced in: *Hydrogeology of the Tully Valley and characterization of mudboil activity, Onondaga County, New York.* Kappel WM, Sherwood DA, Johnston WH. 1996. US Geological Survey. Water Resources Investigations Report 96-4043.

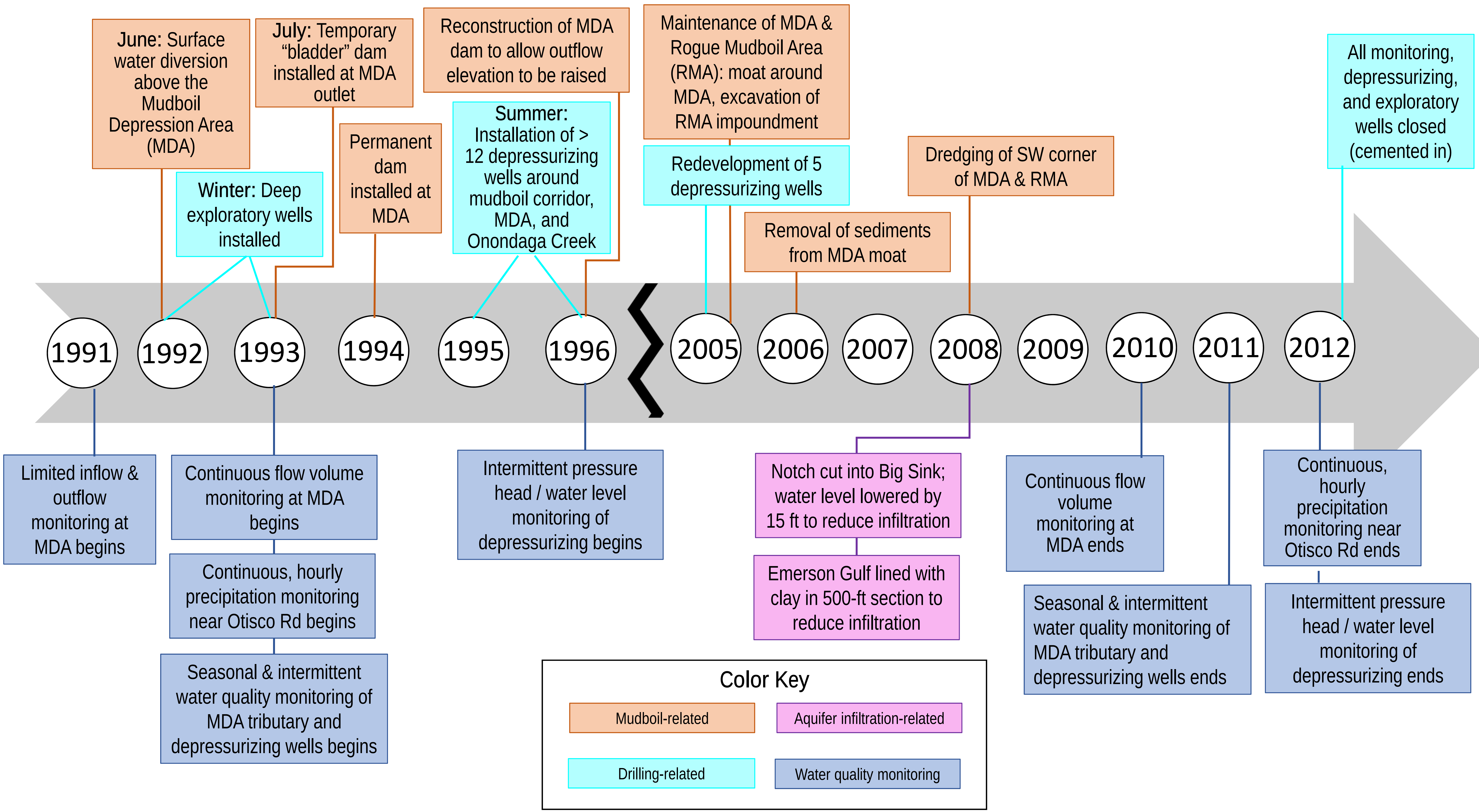


Figure 4. US Geological Survey work in the Tully Valley (1991-2012). MDA= Mudboil Depression Area; TV = Tully Valley.

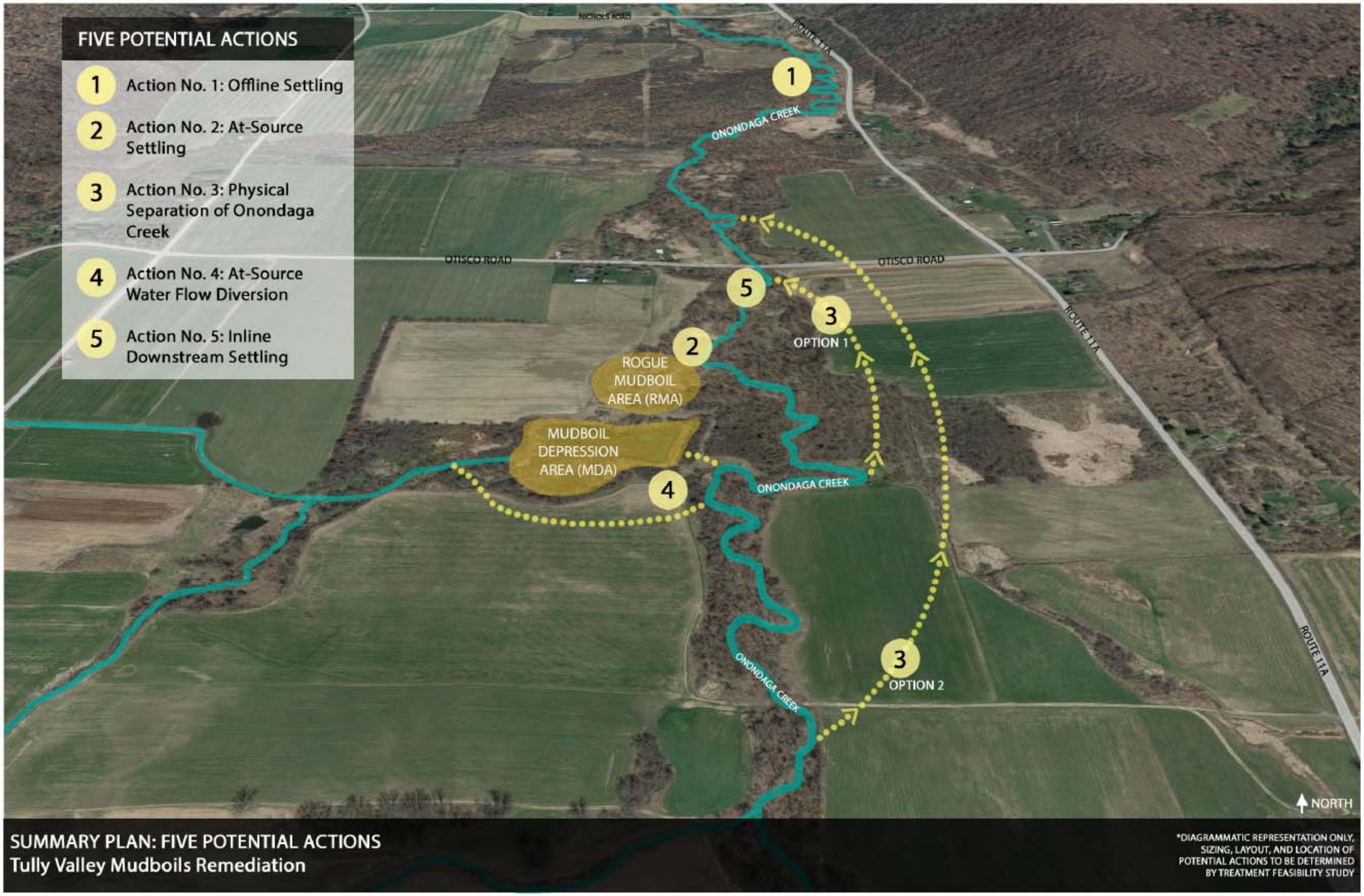


Figure 5. Potential actions summary plan for mudboil mitigation.

The following sections describe the five potential actions and the assigned ranking according to the selection criteria:

1. Offline Settling (ex. constructed engineered settling basins)

Offline settling technology involves the diversion of baseflow from Onondaga Creek at a location downstream of known mudboils to offline settling basins at which suspended sediments are settled out (Figure 6). A treatability study and/or feasibility study (FS) would be needed to identify sizing, detention times, and potential enhancements to achieve treatment objectives. It is understood, however, and assumed that accomplishing offline settling of large masses of sediments and the associated operations and maintenance to include regular removal and transport off-site of accrued sediments would require large-volume, constructed (e.g. concrete) settling chambers and associated means of access for equipment and vehicles. This option involves fairly conventional water/wastewater treatment processes and thus has high probability for effectiveness for managing the highest fraction of mudboils sediment which is known to be associated with baseflow conditions. However, constructing such a facility of sufficient capacity to manage wet weather flows is infeasible and would necessitate a system bypass for high flow conditions and large storm events. Because sediments carried by waters above the baseflow would not be managed, this action is unlikely to achieve high effectiveness. A potential location for this action is the west side of Onondaga Creek immediately south of Nichols Road (Figure 7).

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: Industrial offline treatment technologies would be incompatible with the rural environment for numerous reasons including harden surfaces, mechanical operations, pumps, piping valves, the potential for chemical additives, etc. A more naturalized wetland system would still require baseflow diversion into the offline system[12]. Diversion of baseflow implies that the creek bed will be dry immediately downstream of the diversion during dry weather periods. Any low flow condition used to maintain connectivity is likely to be impaired water quality due to mudboil impacts. Depending on the location of the facility and other factors, it is possible that the dry creek condition might be mitigated by diverting flow from a nearby tributary into the main dry channel at the point of base flow diversion into the offline settling basins. However, direct connection to upstream water and the allowance of fish passage during base flow would not be practical. For the above reasons, this action is considered to have **low environmental compatibility**[13].

III. Administrative Implementability: Although the purpose of siting an offline facility is to improve water quality, an industrial offline settling facility would require a State Pollutant Discharge Elimination System (SPDES) permit and USACE permits for water diversion and instream structure. Hence, landowner and regulatory siting, permitting and operational issues result in **moderate administrative implementability**.

IV. Technical Implementability: Offline water treatment facilities/basins have **moderate** technical implementability due to the size and scale required to accommodate and treat the large volumes of

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[12] An engineered wetland could be used to polish effluent from an offline setline system before discharging to Onondaga Creek. Likewise, the concept of offline wetland creation to handle base flow conditions could also undergo further exploration.

[13] Industrial offline water treatment facilities lack environmental compatibility due to the scale and tankage required to treat the large volumes of water necessary to effectively mitigate mudboil activity.

water necessary to effectively mitigate mudboil activity on a continual basis. The **technological implementability** are anticipated to be **moderate** due to regulatory, land owner, and issues of flooding and operational dynamics.

V. Permanence: This action also has the potential, if properly designed and maintained, to have **high permanence,** i.e. to be a long-lived solution to sediment loads to the creek from the mudboils.

VI. Adaptability: As summarized in the matrix below, this alternative is also **highly adaptable** with respect to changing site conditions. That is, by virtue of its location downstream of areas of all known mudboil activity, the system if property designed will be capable of treating mudboils that occur in areas south (upstream) of the treatment facility. This technology is highly adaptable for addressing future mudboils occurring upstream due to its downstream location. It is also highly reversible as offline structures are easily disconnected and former flow regimes can be returned to prior conditions; however, complete removal would come at a cost.

VII/VIII. Cost: Costs of construction, operation and maintenance, and removal are expected to be **high**. The addition of coagulants and flocculants, if necessary, would require complicated systems and trained operators on a continual basis.

Table 1. Screening matrix for Offline Settling Action.

	Offline Settling
I. Effectiveness	
II. Environmental compatibility	
III. Administrative Implementability	
IV. Technical Implementability	
V. Permanence	
VI. Adaptability	
VII/VIII. Cost	

SECTION:
Settling Basin w/ Post-Settling Wetland

Figure 6. Settling basin schematic. This cross-sectional view depicts a generic longitudinal view that would contain the forebay and polishing wetland of Figure 7.

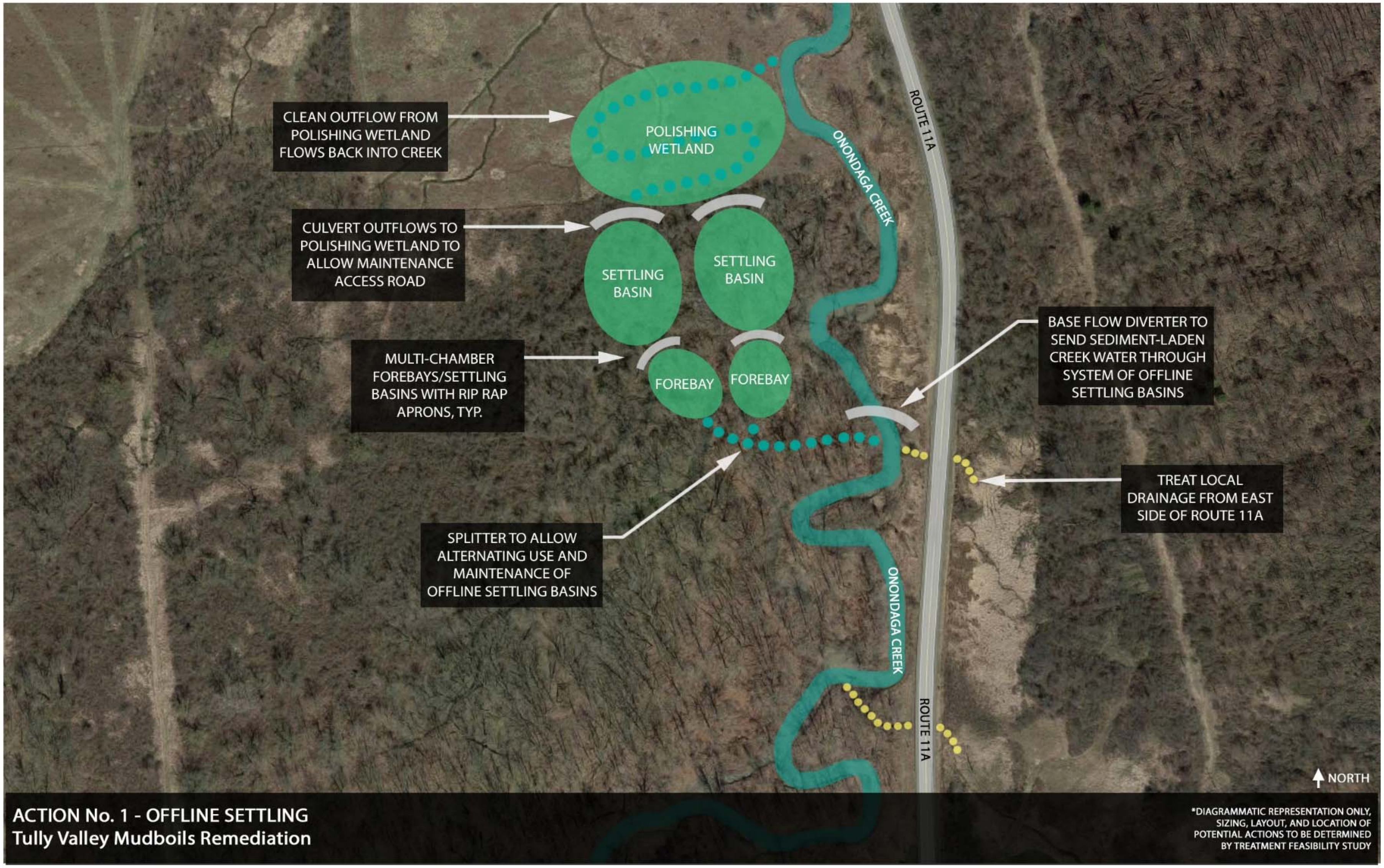

Figure 7. Offline settling system schematic (depicted location is just south of Nichols Road).

2. At-Source Settling (e.g., Physical barrier at Rogue MB [Soft]) (Not crossing creek)

This technology involves the establishment of a physical barrier at active mud boil areas (e.g., the "RMA") or immediately downgradient of historic mud boil(s) activity (Figure 8). The barrier which can either be a "soft" measure (e.g. an inflatable barrier) or "hard" such as a firm wall constructed of earth fill, steel sheet pile or similar material. Sheet piling as a barrier was discussed and dismissed as a potential option, as was any option that penetrated the subsurface. Earthen structures would be preferred over pilings due to the unstable nature of substrates at the MDA, and the recent history of depressurizing well subsidence (see uncertainty discussion on page 6). Nevertheless, a barrier will detain and pond sediment-laden water to allow settling of solids prior to discharge of cleaner water to the Creek (Figure 6). Both the bladder and earth dams are previously demonstrated mitigation technologies, as both were implemented in 1993 to control mudboil discharges. Earth dam construction at the MDA was effective for nearly a dozen years. Then in the mid-2000s, rogue mudboil activity developed outside the MDA impoundment dam, in part, as result of the installation of depressurizing wells. Also, the accumulation of sediments inside the dam may have led to the establishment of overburden causing resistance and thereby, the translocation of emerging mudboils outside the containment area. Hence, precaution should be noted with respect to advancing a potential action that requires ground penetration. Still the structural integrity of the earth dam is sound over 25 years post-construction.

The effectiveness is dependent upon the location, size, retention time, and ability of the retention pond to settle solids. This mitigation technology can be highly effective absent of mudboil activity within Onondaga Creek and under low flow conditions. Because mudboils have occurred in the creek, the effectiveness of this action is diminished and would be considered moderate[14].

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: Depending on availability of land area and cost, this action can be supplemented with a post-settling polishing wetland (see figure below) to improve its effectiveness; yet more likely to improve its **environmental compatibility** to **moderate.**

III. Administrative Implementability: As an action already having been implemented at the MDA, the technical and regulatory aspects of the action are well understood and simply navigated, and thus this action is considered to have **high administrative implementability**.

IV. Technical Implementability: As an action already having been implemented at the MDA the technical and regulatory aspects of the action are well understood and thus this action is considered to have **high technical implementability**.

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[14] The dam structure may be required to directly impound Onondaga Creek flows, which would be tantamount to an in-line settling basin. Due to the areal size and dam height required to manage base flows of Onondaga Creek, the impoundment would need a high flow spillway. Hence, mudboil sediment would be released downstream during high flows. Because the period of sediment capture would be limited to base flow conditions, this action was considered to have moderate effectiveness. Should the dam structure impound Onondaga Creek flow as outlined under this Potential Action 2: At Source Settling, then this potential action is the same as Potential Action 5: Downstream Inline Settling, except for location.

V. Permanence: This action also has the potential, if properly designed and maintained, to have **high permanence,** i.e. to be a long-lived solution to sediment loads to the creek from the mudboils. Because this alternative is by definition targeted to existing, known areas of mudboil activity, this action would require continuous monitoring and the implementation of additional measures if and as new mudboil activity occurs.

VI. Adaptability: Because the action is relatively low in cost (Table 2), the potential exists that subsequent similar measures could be implemented at differing and multiple locations in response to such future mudboil activity, with certain limitations (e.g. instream mudboils). This action is reversible as any structure to impound mudboil discharges could be removed, if practical. Because mudboils have occurred in the creek and are likely to continue occurring in the creek, this action is considered to have **moderate adaptability.**

VII/VIII. Cost: As a small-scale intervention, this potential action is estimated to have **low costs**. Construction costs would be relatively low. Regularly scheduled maintenance would be required in order to remove accumulated sediment deposits. The accumulation of sediments behind the earth dam has been cited as one of the potential reasons rogue mudboil activity occurred outside the MDA. The filling in of the MDA basin with overlying substrates may have contributed to increasing resistance to upwelling as the path of least resistance was relocated outside the MDA and expressed at the RMA. The costs of sediment removal would be relatively low providing relocation would be on-site such as the MDA.

Table 2. Screening matrix for At-source Settling Action.

	At-source Settling
I. Effectiveness	🟡
II. Environmental compatibility	🟡
III. Administrative Implementability	🟢
IV. Technical Implementability	🟢
V. Permanence	🟢
VI. Adaptability	🟡
VII/VIII. Cost	🟢

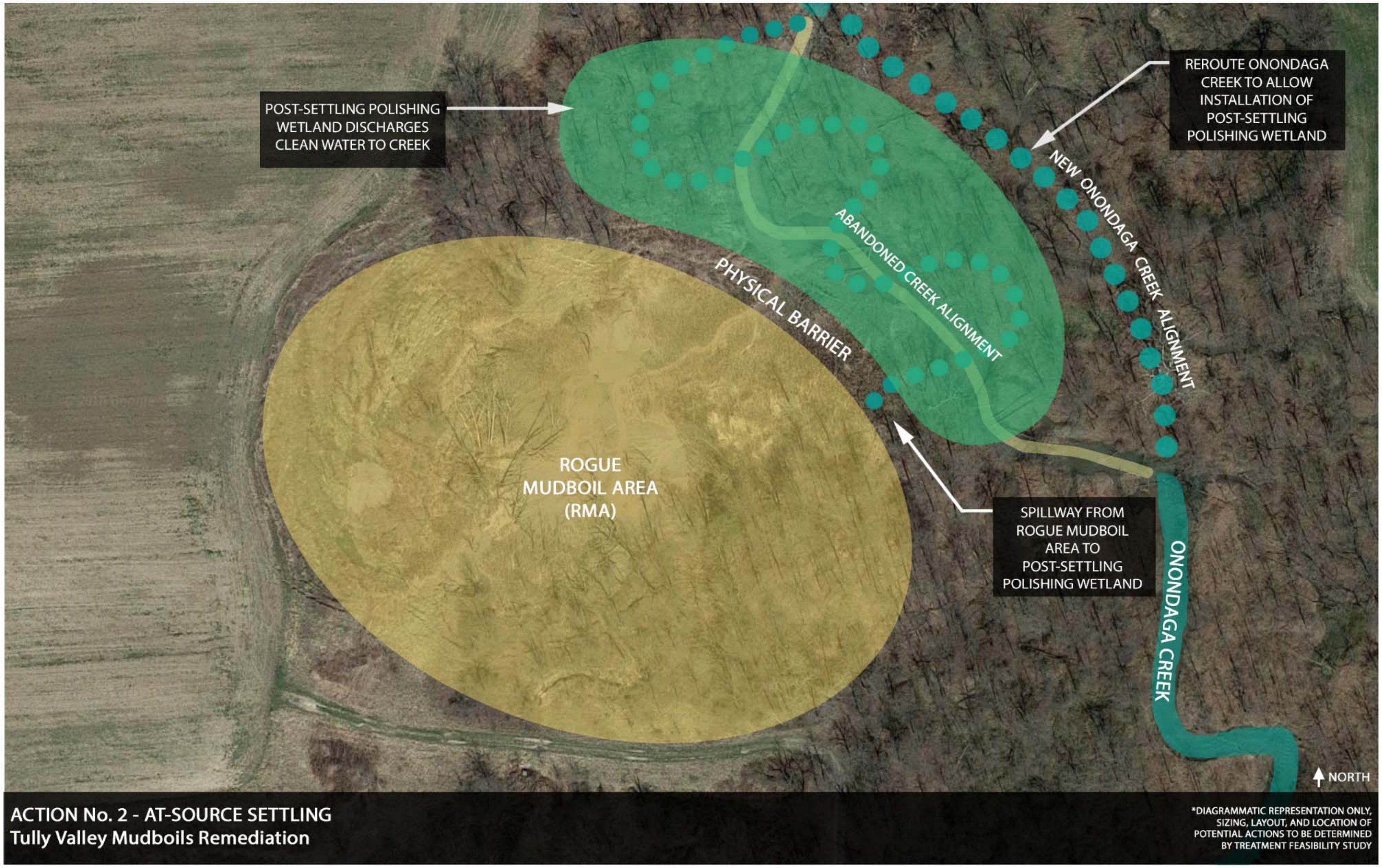

Figure 8. At-source settling basin schematic.

3. Physical separation of Onondaga Creek from Mudboils (ex. rerouting of Onondaga Creek)

Physical separation of Onondaga Creek from mudboils sediments can take the form of a number of specific technologies including:

1. Slurry wall/grout separation of the creek[15]
2. Conduit pipe of creek through active mudboils[16]
3. Relocation of the Creek away from mudboil activity

The three alternative technologies above are considered to have equivalent potential effectiveness with respect to mitigation of loading of mudboil sediments to Onondaga Creek. However, the slurry wall/grout separation and the piping or channelization of the creek through active mudboil areas both have less environmental compatibility and are more challenging with respect to technical implementability than the creek relocation (rerouting) alternative under this technological classification. In addition, physical separation options 1 and 2 were dismissed for varying reasons outlined in the associated footnotes.

A principle reason for dismissing both options is the instability of the valley floor and likelihood of exacerbating mudboil activity and land subsidence as a result of implementing either of the proposed actions. Only the creek location option has the potential to avoid the areas of historic and active mudboils and land subsidence. Consequently, the creek relocation potential action was carried through for further evaluation in this analysis as sole representative of this class of technologies. A more naturalized and acceptable technology for physical separation involves the rerouting of a portion of Onondaga Creek to the east or west beginning at a point upstream (south) of the mudboil depression area (MDA) and rejoining the existing creek channel at a location as far as practical to the north and away from historic mudboil activity. Uncertainty associated with moving the creek needs to be evaluated as the hydrologic dynamics between surficial and ground waters may be influential in establishing conditions favorable to the occurrence of mudboils. Hence mudboil activity may follow proximate to the relocated creek channel.

Two potential options for physical creek separation are presented in this study (Figure 9, Figure 10). Depictions represent general approaches and do not necessarily reflect actual locations. The concept of separation essentially involves creating a buffer of vegetated land between the areas of mudboil activity and a rerouted Creek. Buffer areas are proven technology for mitigating discharge of pollutants including sediments to surface waters with the effectiveness determined by the dimension of the buffer

[15] Slurry wall/grout separation of the creek through active mudboils was eliminated from consideration due to the lack of environmental compatibility, distances required to effectively move water, the potential for substrate instability during construction and system failure or partial collapse, and the high likelihood of mudboil sediment laden waters discharging to the creek at a subsequent downstream location. Even if a harden channel or canal were successfully built to carry upstream Onondaga Creek waters through and past the mudboils, the likelihood of subsidence or exacerbated mudboil to occur as result of unstable substrates is a concern. Likewise, waters discharged from the mudboils would migrate downstream and unite with the natural streambed; hence, some additional supplemental measure would still be required to mitigate mudboil activity (see uncertainty discussion on page 6). Supplemental action alone does not warrant elimination from consideration; however, other potential actions were deemed to be as effective with less overall risk and greater environmental compatibility.

[16] Construction of a conduit pipe carrying the creek through the area of historic and active mudboils was eliminated from further consideration for the same reasons as building a harden sluice or aqueduct. The physical separation of piping Onondaga Creek through the areas of mudboil activity was dismissed outright by the design team due to its very low environmental capability, and low technical implementability due to its difficulty in handling flood water, along with the high likelihood of further mudboil and land subsidence impacts.

area and pollutant loading. The greater the linear distance between sediment source and the creek, the greater the likelihood discharges will settle. Exact distances required would be calculated based on particle sizes, specific gravities, and suspension times. Should the creek be moved and separated from mudboil activity such that upstream waters bypass the MDA and RMA, then downstream water quality would essentially equal that of upstream water quality.

I. Efficacy - potential effectiveness: HIGH

II. Environmental compatibility: Creating a new naturalized creek can be **highly compatible** with the surrounding environment[17].

III. Administrative Implementability: Permitting and land acquisition represent challenges with respect to this action thus suggesting the action has **low administrative implementability.** Figure 11 shows mudboil area property ownership.

[17] Understanding stream characteristics, heterogeneity, and mechanics at work can help avoid problems associated with natural stream channel relocation such as heightened erosion or deposition, hanging tributaries, vegetation loss, water quality issues and subsequent ecological impacts (Flatley, Rutherfurd, & Hardie, 2018).

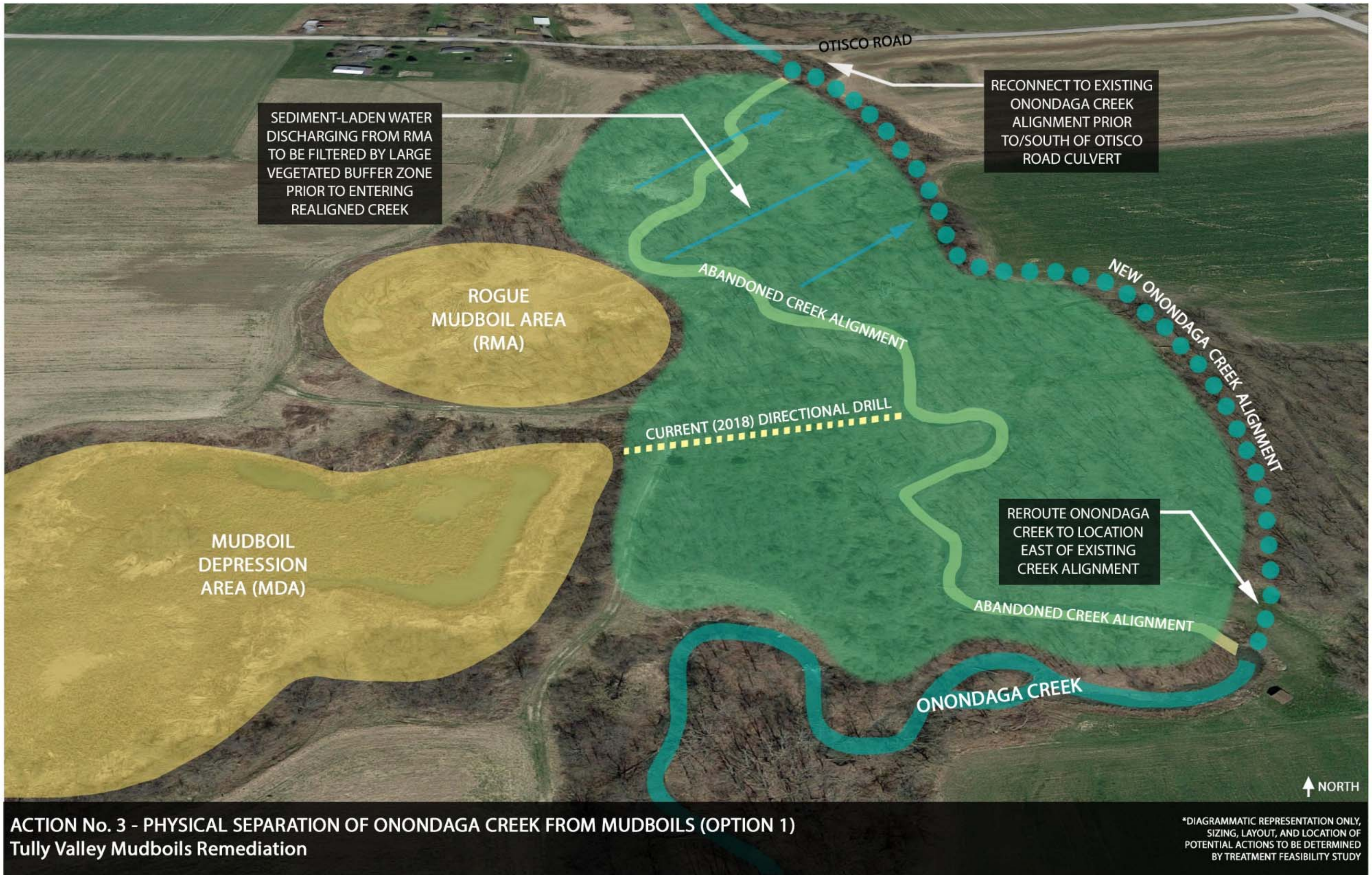

Figure 9. Creek separation schematic, Option 1.

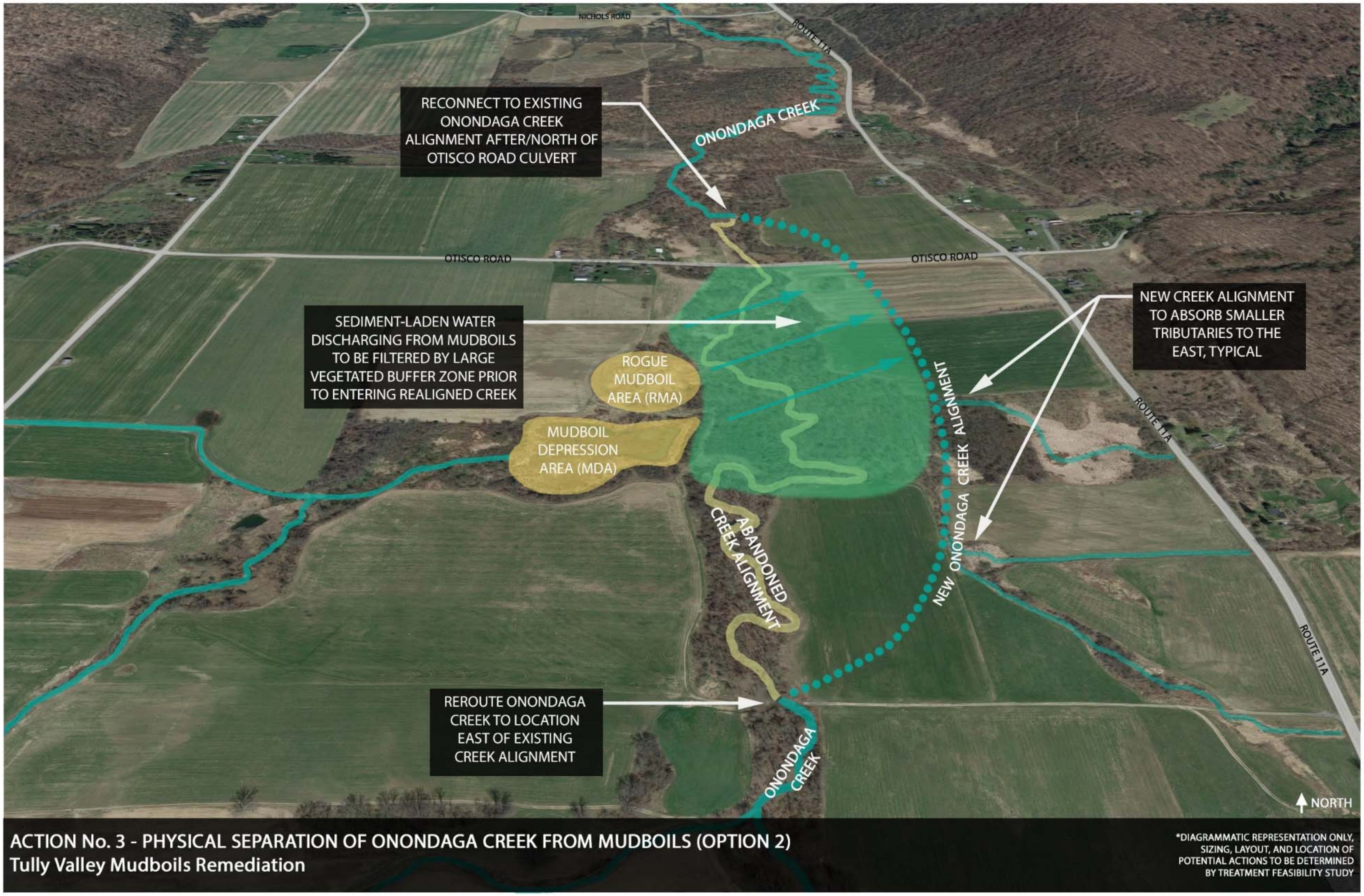

Figure 10. Creek separation schematic, Option 2.

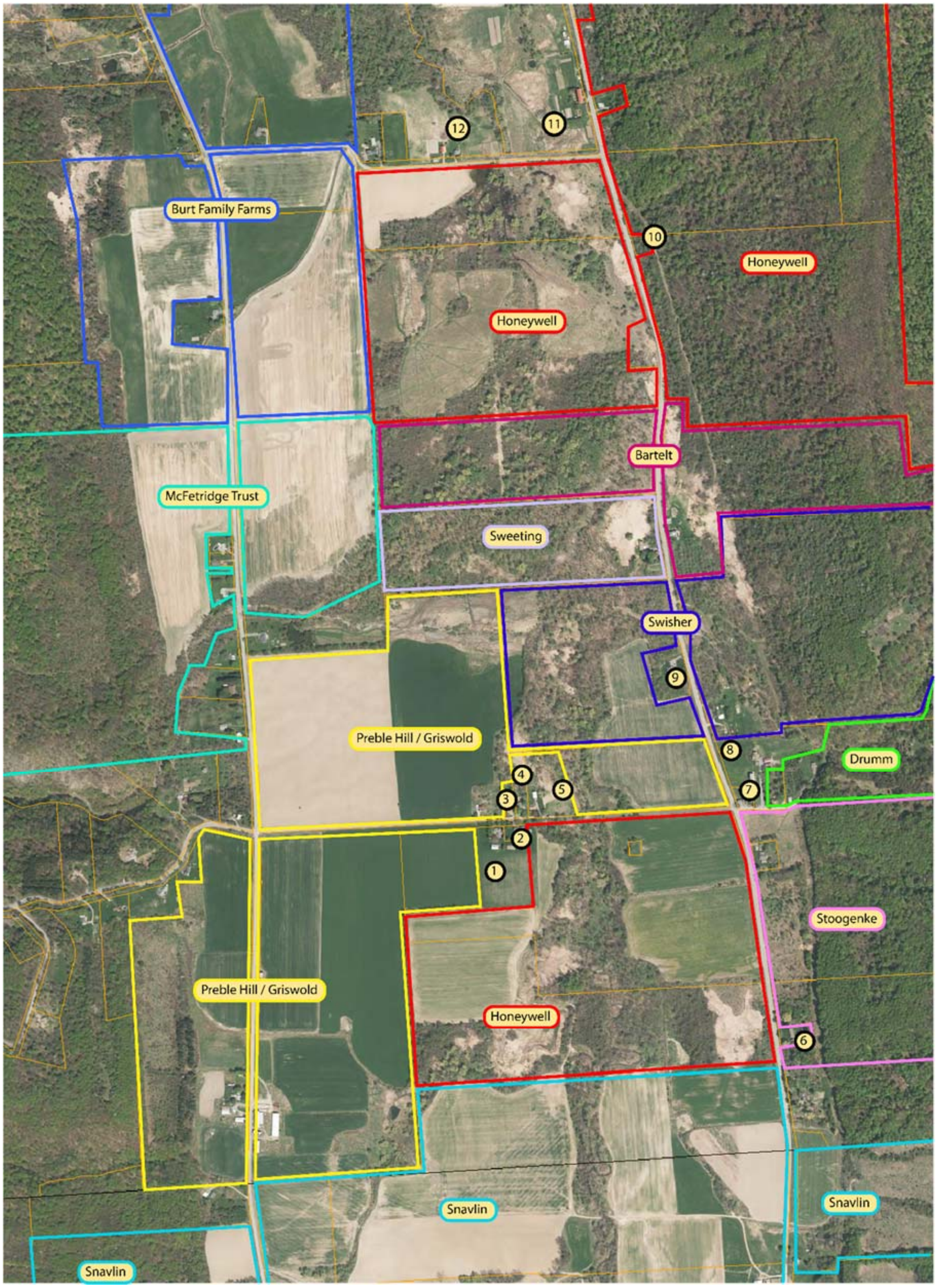

Figure 11. Mudboil Area Parcel Ownership.

Figure 11: Mudboil Area Parcel Ownership

This index corresponds with the demarcated map of parcel boundaries in the Tully Valley mudboil area. Major landowners are given direct labels on the map, with contact information referenced here in the corresponding boundary color. Small residences in the considered area are labeled 1-12, with contact information referenced here as well (this information may be dated).

Honeywell:
Honeywell International Inc.
PO Box 71970, Phoenix, AZ, 85050

Snavlin:
John R Snavlin, Richard G Snavlin Sr
1560 Route 11A, Tully, NY, 13159

Preble Hill / Griswold:
Preble Hill Acres LLC owned by Griswold family
PO Box 15, Preble, NY, 13141

Stoogenke:
Michael S Stoogenke, Darcy Sachs
1802 Route 11A, Tully, NY, 13159

Drumm:
Robert A Drumm, Ruth M Drumm
5633 Drumm Road, Tully, NY, 13159

Swisher:
Paul W Swisher, Stephen W Swisher
1900 Route 11A, Tully, NY, 13159

Sweeting:
Sandra L Sweeting, Jeanne E Sweeting
1915 Route 11A, Tully, NY, 13159

Bartelt:
Cory Bartelt, Rebecca G Bartelt
10315 Tecumseh Lane, Fairfax, VA, 22030

McFetridge Trust:
William McFetridge I
8483 #5 East Road, Fabius, NY, 13063

Burt Family Farms:
Randy E Burt, Elaine F Burt
5335 Nichols Road, Tully, NY, 13159

Residence 1:
Timothy L Negley, Sherry I Negley
5450 Otisco Road, Tully, NY, 13159

Residence 2:
Robert J Zgardzinkski
5445 Otisco Road, Tully, NY, 13159

Residence 3:
Hans Smid, Mary Smid
5463 Otisco Road, Tully, NY, 13159

Residence 4:
Timothy E Richards
5461 Otisco Road, Tully, NY, 13159

Residence 5:
Richard D Gillette
5459 Otisco Road, Tully, NY, 13159

Residence 6:
Nicholas E Pistillo
1710 Route 11A, Tully, NY, 13159

Residence 7:
Marilyn D Mackey, Leonard P Mackey
1810 Route 11A, Tully, NY 13159

Residence 8:
Micheline A Derr
5621 Drumm Road, Tully, NY, 13159

Residence 9:
Property Address: 1903 Route 11A
Covenant Housing Corp
1228 Teall Ave, Syracuse, NY, 13206

Residence 10:
Property Address: Route 11A
Christopher Taddeo
356 Main St, Minoa, NY, 13116

Residence 11:
Daniel B Button, Stephanie S Button
2113 Route 11A, Tully, NY, 13159

Residence 12:
Robert J Pierpoint, Susan E Pierpoint
5433 Nichols Road, Tully, NY, 13159

Creek relocation is a technique that has been performed elsewhere (Endreny and Soulman 2011Need citations – see useful documents folder) and will require maintenance[18]**.** Nevertheless, creek and watershed manipulations have not been applied as a solution to mudboil activity, as mudboils do not exist elsewhere. No information was located in the available literature pertaining to the occurrence of cool ground water vents under artesian pressure. Likewise, no information was located in the available literature regarding stream restorations in similarly unstable substrates. Nevertheless, inherent risks associated with instability of the valley floor and the potential for mudboil activity and land subsidence to follow the creek relocation need to be examined should this potential action be recommended for FS. A proposal to reroute the creek was presented by USGS in 2010 in response to the emergence of rogue mudboil activity. However, the project was not implemented due to uncertainty of success, concerns for exacerbation and transference of mudboil and subsidence activity to the new creek location along with insufficient funds.

IV. Technical Implementability: The proven state of the science of creek relocation combined with the mitigating factor of this unprecedented application to mitigation of mudboil sediment loading, as well as consideration of the above environmental uncertainties and risks, suggests that this action has **moderate technical implementability**. The farther the distance between the relocated stream bed and the old streambed, historic (MDA) and active mudboils (RMA) and land subsidence, the less likely the future occurrence at the new location. The potential for the newly situated surface water body to cause future mudboil activity due to the local hydrogeology would need to be evaluated.

V. Permanence: The potential distance that the Creek can be rerouted to the east is constrained by the creek valley i.e. the rise in land elevation to the east. Figure 12 depicts the 170m contour[19] in relation to Onondaga Creek on the TIN map showing a 10m elevation rise in land surface. Figure 13 depicts Tully Valley land elevations south of Route 20. Because the topography and land use in the area limit the distance that the creek can be moved from the mudboils, the potential that mudboils sediment will eventually migrate downstream to the original creek channel is a concern, thus this potential action is considered to have **low permanence.**

VI. Adaptability: As presented in the summary matrix below, this alternative, by moving the creek a significant distance from known areas of mudboil activity is considered adaptable with respect to changing site conditions but only **moderately adaptable**, depending on the potential for new mud boils to occur and where those occurrences are relative to the relocated creek. The closer the new stream channel to recent and historic mudboil activity, the greater the risk of re-occurrence of present conditions. The potential for mudboil activity to occur subsequent to creek relocation, remedial efforts or other forms of human intervention is eminently probable based on historical incidence (refer to page 6, *Uncertainty Discussion*). This action is reversible as creek flow can be returned to the historical stream channel.

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[18] Understanding stream characteristics, heterogeneity, and mechanics at work can help avoid problems associated with natural stream channel relocation such as heightened erosion or deposition, hanging tributaries, vegetation loss, water quality issues and subsequent ecological impacts (Flatley, Rutherfurd, & Hardie, 2018).

[19] The 170m contour is identified as a point of reference only, and for the purposes of this document show the general land topography that would confine stream relocation depending on the upstream point of intercept.

VII/VIII. Cost: Despite low maintenance and moderate technical implementability[20], this potential action has a relatively **high cost of construction and implementation**. In addition, land acquisition fees may also be required.

Table 3. Screening matrix for physical separation (Creek Relocation) Action.

	Creek Relocation
I. Effectiveness	🟢
II. Environmental compatibility	🟢
III. Administrative Implementability	🔴
IV. Technical Implementability	🟡
V. Permanence	🔴
VI. Adaptability	🟡
VII/VIII. Cost	🔴

[20] The TAG was grappling with two issues for this action as it relates to effectiveness and permanence. The first was migration of sediment from known areas of mudboil activity (which we address under "permanence") and the second was the potential occurrence of new mudboils (addressed under adaptability). With respect to the first: in theory when creating buffer strips (which is essentially what we are doing) if you create enough land buffer to accommodate the loading that will be experienced, the technique will be effective. We are constrained however, as noted above so it would seem to limit the technical implementability of this alternative which contributes to its lack of permanence. So should we consider this to have moderate technical implementability when the challenges of creating a new creek are also considered.

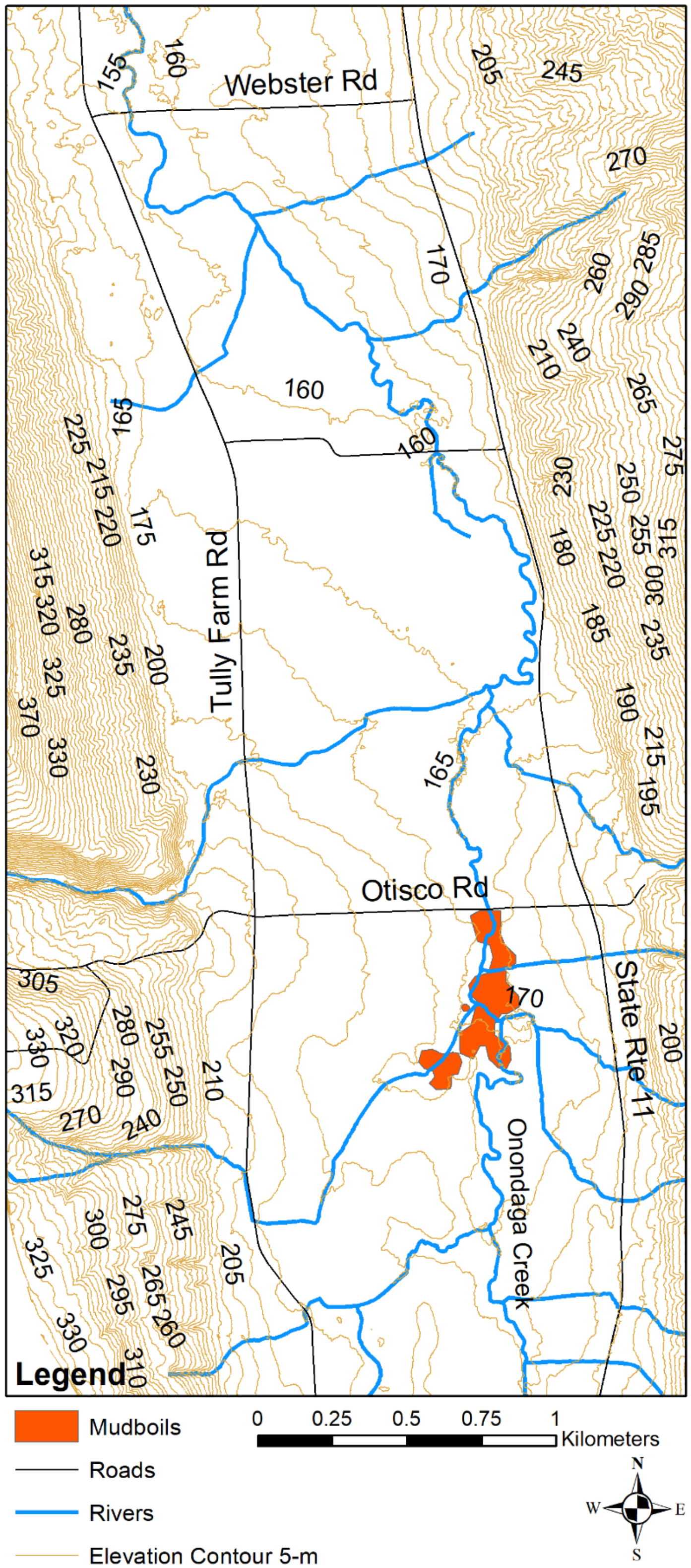

Figure 12: TIN map 170m contour in relation to Onondaga Creek. Map provided by Dr. Ted Endreny, SUNY ESF.

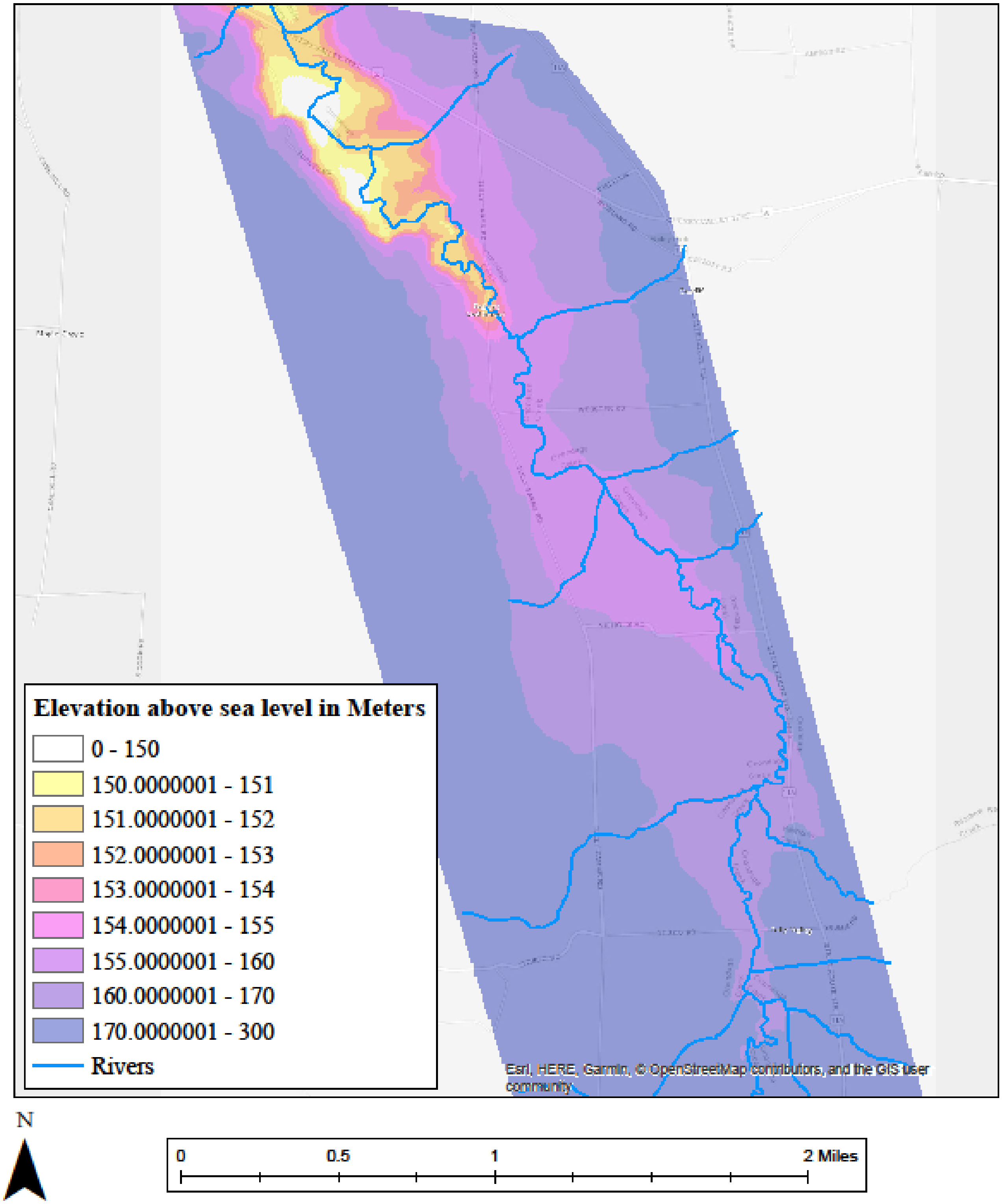

Figure 13: Tully Valley land elevations south of Route 20.

4. At-source water flow (Q) diversion

The objective of this technological option would be to redirect source water entering the MDA from the surrounding drainage basin to reduce volume of water flowing through active RMA (Figure 14). By eliminating or greatly reducing source water to areas of mudboil activity, the source of sedimentation to Onondaga Creek can be mitigated. Examples of this concept applied to the mudboils include: 1) Diverting flow at the MDA in a manner similar to the 2018 directional drill project, located as identified in the TVGT report, and 2) redirect flow entering MDA in a manner analogous to 1993 tributary relocation to the south. Recent evidence suggests pre-1993 remedial drainage patterns may have re-established to some extent over the interim period. Further, this potential action does not address mudboil activity in the creek[21], otherwise, this potential action is synonymous with creek relocation.

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: This action would be visually unobtrusive and is thus considered **highly compatible** with the surrounding environment.

III. Administrative Implementability: Permitting and access hurdles are low and thus this action has **high administrative implementability.**

IV. Technical Implementability: As noted above, the technology has been applied previously and thus has **high technical implementability**.

V. Permanence: If properly maintained, this potential action is considered to have **high permanence** with respect to known areas of mudboil activity targeted by this action. As noted, in the absence of proper maintenance, natural drainage systems can re-establish old flow patterns.

VI. Adaptability: The technology is potentially adaptable to the occurrence of new mudboils depending on the location, but the efficacy of this potential action would be low should a mudboil break out, as in the past, within Onondaga Creek. Further, the potential for mudboil activity to occur subsequent to remedial efforts or other forms of human intervention is eminently probable based on historical incidence (see uncertainty discussion on page 6). (Figure 15 shows a map of known and suspected mudboil activity.) Still there are multiple locations at which surface water flows can be diverted away from existing mudboils. Therefore, this alternative is considered to have **moderate adaptability**. This action is reversible as diverted flows can be returned to historical stream channels.

VII/VIII. Cost: As noted above, the technology has been applied previously at **low cost**.

[21] This option is not effective for mudboils situated in the creek.

Table 4. Screening matrix for source water diversion action.

	Source Water Diversion
I. Effectiveness	🟡
II. Environmental compatibility	🟢
III. Administrative Implementability	🟢
IV. Technical Implementability	🟢
V. Permanence	🟢
VI. Adaptability	🟡
VII/VIII. Cost	🟢

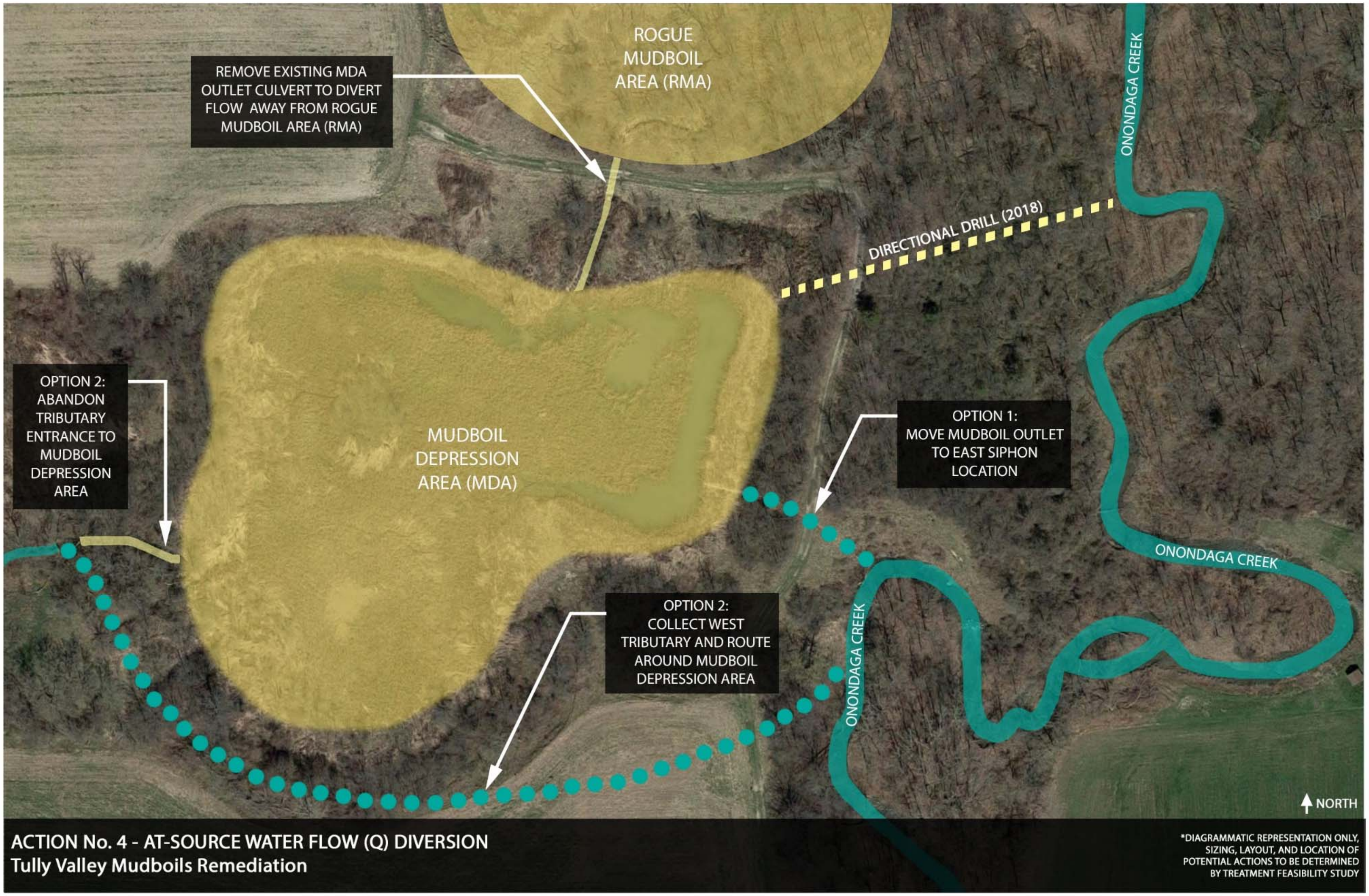

Figure 14. At-source water diversion schematic.

Figure 15: Map of known and suspected mudboil activity (USGS 2014). Top: south end of mudboil corridor; bottom: north end of mudboil corridor.

5. Inline Downstream Settling [Downstream of Mudboil Activity]

This option involves the creation of one or a series of settling impoundments/reservoirs by damming Onondaga Creek downstream of known mudboil activity. Just as with Potential Action 2: At-Source Settling[22], an earth dam would be the preferred structure. Figure 16 shows a damming structure located at Otisco Road, which would take advantage of land contours in establishing a wetland basin and settling pond for mudboil sediments. Depending on size and scale of the containment area, this action has the potential to be highly effective under base flow conditions.

I. Efficacy - potential effectiveness: HIGH

This action involves creation of a reservoir/impoundment which is considered aesthetically compatible with the general surroundings. A single dam depending on containment volume may lose effectiveness during higher flow or extreme storm events. However, properly designed settling pools can accommodate greater than baseflow volumes, and therefore, this option has the potential to be more effective than off-line settling. A variation of this potential action is to develop a series of low head dam structures that create a string of shallow wetlands. A series of settling pools could potentially increase the overall effectiveness of higher flows. This would require further study to identify whether a series of low head dams is feasible. Yet the potential for mudboil activity to occur subsequent to remedial efforts or other forms of human intervention is eminently probable based on historical incidence. In fact, land subsidence in May of 1991 and proximate mudboil activity led to the collapse and subsequent deck removal and closure of Otisco Road (see uncertainty discussion on page 6). Consequently, the dam location depiction in Figure 15 represents a general approach and does not necessarily reflect the actual location. Dam(s) placement could be further to the north to avoid historic mudboil activity; however, land ownership and infrastructure issues could make siting more difficult.

II. Environmental compatibility: This alternative is considered to have **moderate environmental compatibility**; a major reason would be the increase in water temperature impounded behind the dam, thereby causing a downstream warming effect via the discharge of lentic water into a lotic system. Ponding of flowing waters results in the warming of those waters which is ecologically incompatible with a creek in which a goal exists for trout restoration. Still a naturalized wetland or system of wetlands can be constructed to induce settling, but also provide flood storage and habitat, spawning and nursery grounds for fish and wildlife. A salt marsh community could be established to mitigate saline discharges associated with mature mudboils.

III. Administrative Implementability: Permitting for the damming of a creek and acquisition of land at which water will be impounded are considered to be significant hurdles for this potential action and thus this action is considered to have **low administrative implementability** due to regulatory issues involving impacts of damming a stream.

IV. Technical Implementability: Sedimentation basins are a common mitigation technique, although usually at a lesser scale than what is proposed herein, thus this technology is considered to have **low technical implementability** due to the necessary size requirements needed to control large volumes of

[22] Should the dam structure impound Onondaga Creek flow under Potential Action 2: At Source Settling, then Potential Action 5: Downstream Inline Settling is the same except for location.

water in order to obtain proper settling, dam safety hazards, and the complexity of design. Yet, a low head or series of low head wetland basins might be achievable for base flow conditions. A series of wetlands may necessitate the bypass of high flow events. Again, further study would be necessary to determine feasibility of operating and maintaining a wetland series of low head dams.

V. Permanence: If properly maintained, this potential action is considered to have **high permanence**.

VI. Adaptability: Similar to the offline settling basins alternative, this alternative would address sedimentation from existing, known areas of mudboil activity and would also address future occurrences of mudboils, if occurring within the generally recognized areas where mudboils might occur and thus this alternative is considered to have **high adaptability**. This action is reversible as any damming structure can be removed and creek flow can be returned to the historical stream channel.

VII/VIII. Cost: Capital construction and land acquisition costs would result in this action having **high cost**. Relatively low periodic maintenance costs of dredging and disposal of sediment deposits back into the MDA are expected to be incurred on somewhat regularly-timed intervals.

Table 5. Screening matrix for source water diversion action.

	Inline Settling
I. Effectiveness	🟢
II. Environmental compatibility	🟡
III. Administrative Implementability	🔴
IV. Technical Implementability	🔴
V. Permanence	🟢
VI. Adaptability	🟢
VII/VIII. Cost	🔴

Figure 16. Inline downstream settling schematic.

B. Screening Analysis

As presented in the previous sections, the five potential actions evaluated exhibit varying levels of performance relative to screening against the "selection criteria" with none of the potential actions exhibiting high favorability across all selection criteria.

This section of the analysis presents the screening of the five potential actions identified in Section A combined with other potential or supplemental actions[23]. A supplemental action is defined as any action added to one of the five potential actions in order to improve performance as measured against the selection criteria. At this level of analysis, the criteria **III. administrative implementability** and **VII/VIII. cost** are not determined to be discriminating in terms of the viability of implementing any of the potential actions and thus these selection criteria are not carried further through this screening level analysis. Each of these selection criteria will be examined in depth for the potential action(s) selected as a result of this *Analysis of Alternatives* at the subsequent *FS*.

The DT combined two of the five potential actions or added a supplemental action to be performed along with a single potential action as a means of achieving downstream water quality goals and satisfying the remaining selection criteria[24] of:

I. Effectiveness,
II. Environmental Compatibility,
IV. Technical Implementability,
V. Permanence, and
VI. Adaptability.

Settling basins and/or constructed wetlands are an important alternative due to the inherent need to settle mudboil deposits and separate the solids fraction from the liquid water.

[23] No single potential action implemented alone achieves the goal of restoring downstream water quality to that of the upstream waters without the added benefits of additional potential actions. For example, physical separation in the form of creek relocation, exhibits high effectiveness relative to the top-level objective of achieving downstream water quality equivalent to upstream water quality with respect to total suspended solids (TSS) and salinity simply by bringing upstream waters around the mudboils. Yet, as a standalone potential option, creek relocation will require additional measures to prevent mudboil discharges from finding the newly located stream bed. The most likely path would be where mudboil discharges found their way downstream and into the newly formed stream bed via the former stream bed. Likewise, other potential actions such as offline line or inline (i.e. wetlands) settling exhibit moderate effectiveness but are more permanent and more adaptable to changes in system conditions, and thus, are potentially more effective in the long term when considering long term performance and uncertainties in the Onondaga Creek/mudboils system.

[24] Not including the selection criteria of III. administrative implementability and VII/VIII. costs; these selection criteria will be examined in depth as part of the *FS.*

Supplemental and Potential Action Combinations: Constructed wetlands[25] was added as a supplemental action that could improve the effectiveness and overall ranking against the selection criteria of at least two of the five potential actions. Likewise, by pairing any two of the five potential actions in combination with each other, effectiveness and overall ranking against the selection criteria could also be improved. The DT evaluated a series of permutations and combinations of the five potential actions and supplemental action of constructing wetlands[26].

The following outline describes the work elements associated with each of the polishing wetland supplemental actions.

---

[25] Constructed wetlands are wetlands constructed to mimic naturally occurring wetlands in form and function in terms of providing natural water treatment processes and aesthetic appeal. For purposes of this analysis such systems are considered to have potential value as supplemental actions when combined with Potential Action 1: Offline Settling, Potential Action 2: At-source Settling, and Potential Action 5: Inline Settling for achieving enhanced environmental compatibility both from an aesthetic standpoint and by providing secondary water treatment beyond primary solids settling. Constructed wetlands are typically built in a series of shallow, densely-planted, man-made ponds that help filter water through physical and biological processes. The wetland ponds provide a natural way to treat and remove pollutants from surface waters including sediments. Constructed wetlands are usually designed in a series of treatments referred to as a treatment train. Trains typically consist of three main treatment components:

- Inlet zone: basin that settles out coarse sediment,
- macrophyte zone: shallow area with dense aquatic plants forming the main part of the wetland, which filters and removes fine particles and dissolved pollutants, and
- high flow bypass channel: excess water flows around the wetland without damaging the system.

Wetlands function at three levels to improve water quality:

- physical,
- biological and chemical uptake, and
- pollutant transformation.

Physical configuration and select macrophytes are essential to capturing fine particles and trapping high proportions of absorbed pollutants attached to sediment.

Proper designs slow water flow, which promotes fine particle settling, and reduces sediment scour and re-suspension. Biological and chemical uptake occurs as microorganisms produce biofilms on plant surfaces, thereby, absorbing and trapping pollutants through enhanced sedimentation and adhesion to fine suspended particles. Wetlands can transform pollutants in a number of ways:

- regular wetting and drying cycles can stabilize and fix contaminants such as nutrients and metals into underlying substrates,
- microbial processes can convert pollutants like ammonium and nitrate into nitrogen gas (nitrification/denitrification), which is released into the atmosphere, and
- ultraviolet (UV) sunlight exposure in open waters can provide chemical transformation and disinfection.

Common constructed wetlands design requirements include:

- particles >125µm settle at the inlet zone,
- majority of the flow volume is directed through the macrophyte zone to enhance sedimentation, filtration, adhesion and biological uptake
- flow detention is >72 hours,
- water velocity is <0.5m/s; hence, the macrophyte zone is protected from scouring and damage to the plants, by passing flows that exceed the maximum extended detention depth
- minimize the frequency macrophytes are inundated to excessive depths, thereby avoiding plant damage and reductions in treatment efficacy
- outlet structure is used to control flow rates

[26] Constructed wetlands are highly environmentally compatible, easily maintained and can be permanent, or can be moved or adapted to changing conditions. Hence, constructed wetlands score well when measured against the remaining selection criteria.

A. Potential Supplemental Actions (continued from the work element outline for potential actions on page 8):

6. Post-Settling Wetland at Nichols Rd (coupled with Potential Action 1: Off-line Settling)

A. Receives waters from the system of alternating settling basins
B. Water is polished through a natural wetland
C. Need to calculate areal size (dimensions) based on Q volume (A = W*L*d)
D. Need to develop hydrologic Q plan
E. Need to develop planting strategy

7. Post-Settling Wetland at Rogue (see Potential Action 2: At Source Settling)

A. Receiving wetland accepting water from settling basin
B. Potentially receive MDA waters
C. Route runoff to MDA or around MDA and Rogue area
D. Need to calculate areal size (dimensions) based on Q volume (A=W*L*d)
E. Need to develop hydrologic Q plan
F. Need to develop planting strategy

Each of the five potential actions was assigned a complimentary potential or supplemental action that improved its ranking against the five remaining selection criteria. The selected combinations were as follows:

Potential Action 1: Offline settling with Supplemental Action: post-settling polishing wetland
Potential Action 2: At-source settling with Supplemental Action: post-settling polishing wetland
Potential Action 3: Physical separation (Creek relocation) with Potential Action 2: At-source settling
Potential Action 4: At-source flow diversion with Potential Action 2: At-source settling
Potential Action 5: Inline settling with Potential Action 2: At-source settling

These combinations of actions were carried through this final screening analysis. Note that no potential combination results with a "low" or less favorable rank when measured against any of the selection criteria.

Potential Action 1: Offline settling with Supplemental Action 6: Post-settling Wetland

The following work elements would be performed in combination.

1. Offline Settling (e.g., Basins at Nichols Rd [Hard])

A. Divert creek into a parallel system of settling basins
B. Diversion and basins accommodate base flow
C. High Q and storm events bypass the system and remain in the creek channel
D. System is designed against flood protection
E. System is maintained by parallel ponds: one pond is drained, sediments are removed and disposed while the other pond is in service
F. Sediments are disposed back into the MDA
G. Water leaves the settling pond and is polished in a natural wetland prior to discharge back into the creek (see Potential Supplemental Action 6).

Action 1b: Develop a series of industrial ponds in parallel (Hard)

6. Post-Settling Wetland at Nichols Rd (coupled with Potential Action 1: Off-line Settling)

A. Receives waters from the system of alternating settling basins
B. Water is polished through a natural wetland
C. Need to calculate areal size (dimensions) based on Q volume (A = W*L*d)
D. Need to develop hydrologic Q plan
E. Need to develop planting strategy

The following section discusses the rationale and net differences in selection criteria rankings.

An offline settling facility with a polishing wetland would still have difficulty in managing wet weather flows and would still require a system bypass for high flow conditions and large storm events. Because sediments carried by waters above the baseflow would not be treated, this action is unlikely to achieve moderate effectiveness.

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: The addition of a polishing wetland would improve the environmental compatibility of this action from low to **moderate**.

IV. Technical Implementability: The technological implementability of this action is anticipated to improve from moderate to **highly favorable** due to increased ability to meet regulatory requirements, and overcome issues of flooding and operational dynamics with the addition of a polishing wetland.

V. Permanence: Both the offline settling system and polishing wetland have the potential, if properly designed and maintained, to have **high permanence,** i.e. to be a long-lived solution to sediment loads to the creek from the mudboils.

VI. Adaptability: This alternative along with a polishing wetland are also **highly adaptable** with respect to changing site conditions. That is, by virtue of its location downstream of areas of all known mudboil activity, the system if property designed will be capable of treating upstream mudboil activity. The addition of a polishing wetland would improve compatibility with the rural environment, but would lessen the reversibility, as it may be more difficult to return established wetland areas to prior conditions.

Table 6 shows the contrast in selection criteria rankings between Potential Action 1: Offline settling as a standalone project versus that performed together with Supplemental Action 6: Post-settling Wetland.

Table 6. Screening matrix for Offline Settling Action/plus wetland.

	Offline Settling	Offline Settling w/ Wetland
I. Effectiveness	🟡	🟡
II. Environmental compatibility	🔴	🟡
IV. Technical Implementability	🟡	🟢
V. Permanence	🟢	🟢
VI. Adaptability	🟢	🟢

Potential Action 2: At-source Settling with Supplemental Action 7: Post-settling Wetland

The following work elements would be performed in combination.

2. At-Source Settling (e.g., Basin at Rogue MB [Soft])

A. Demonstration project
B. Dam of variable size (could be inflatable)
C. Impounded water causes settling at the source
D. Limit/minimize runoff into Rogue area (see Potential Supplemental Action 7)

7. Post-Settling Wetland at Rogue (see Potential Action 2: At Source Settling)

A. Receiving wetland accepting water from settling basin
B. Potentially receive MDA waters
C. Route runoff to MDA or around MDA and Rogue area
D. Need to calculate areal size (dimensions) based on Q volume (A=W*L*d)
E. Need to develop hydrologic Q plan
F. Need to develop planting strategy

Although there will be a known marked improvement in the performance of at-source settling with the addition of a polishing wetland, the actual rankings against the remaining selection criteria went unchanged. The following section discusses the rationale in the selection criteria rankings.

The effectiveness of at-source settling will greatly improve with the addition of a polishing wetland. Therefore, the addition of a post-treatment polishing wetland will be highly effective absent of mudboil activity within Onondaga Creek and under low flow conditions. Yet because mudboils have occurred in the creek, the effectiveness of these combined actions is diminished and for this reason only, these combined actions were considered to have moderate effectiveness:

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: The at-source settling action supplemented with a post-settling polishing wetland (see Figure 14) can improve effectiveness to HIGH and improve a moderate environmental compatibility to a ranking of highly compatible with the environment**.** Yet for the same reason as above, because mudboils have occurred in the creek, these combined actions were considered to have **moderate environmental compatibility**.

III/IV. Administrative Implementability/Technical Implementability: As both actions have been implemented at the MDA and elsewhere, the technical and regulatory aspects of both actions are well understood and thus these actions are considered to have **high administrative implementability** and **high technical implementability**.

V. Permanence: These combined actions also have the potential, if properly designed and maintained, to have **high permanence,** i.e. to be a long-lived solution to sediment loads to the creek from the mudboils. Because these alternatives are by definition targeted to existing, known areas of mudboil activity, these actions would require continuous monitoring and the implementation of additional measures if and as new mudboil activity occurs. Again, the major concern is mudboil activity within Onondaga Creek.

VI. Adaptability: Because these actions are relatively low in cost, the potential exists that subsequent similar measures could be implemented at differing and multiple locations in response to such future mudboil activity, with certain limitations (e.g. instream mudboils). Should new mudboil activity be formed in a proximate location, multiple at-source settling basins could be routed into the same polishing wetland. This action is reversible as any structure to impound mudboil discharges could be removed, if practical. Thus, these combined actions are considered to have **moderate adaptability.**

Table 7 shows the contrast in selection criteria rankings between Potential Action 2: At-source settling as a standalone project versus that performed together with Supplemental Action 7: Post-settling Wetland.

Table 7. Screening matrix for At-source Settling/plus wetland.

	At-source Settling	At-source Settling w/ Wetland
I. Effectiveness	🟡	🟡
II. Environmental compatibility	🟡	🟡
IV. Technical Implementability	🟢	🟢
V. Permanence	🟢	🟢
VI. Adaptability	🟡	🟡

Potential Action 3: Physical separation (Creek relocation) with Potential Action 2: At-source settling

The following work elements would be performed in combination.

3. Onondaga Creek Relocation Around Mudboils

- A. Start the relocation as far upstream as to avoid potential mudboil activity (need maps of Honeywell properties/solution mining wells and fractures) (LiDAR data – map canal)
- B. Rejoin existing creek as far downstream as to avoid potential mudboil activity (greatest linear distance possible South to North)
- C. Move as far to the west/east as to avoid mudboil activity
- D. Combine with other potential actions to settle mudboil activity on-site/utilizing former (currently existing) creek channel

2. At-Source Settling (e.g., Basin at Rogue MB [Soft])

- A. Demonstration project
- B. Dam of variable size (could be inflatable)
- C. Impounded water causes settling at the source
- D. Limit/minimize runoff into Rogue area (see Potential Supplemental Action 7)

The following section discusses the rationale and net differences in selection criteria rankings.

Separating Onondaga Creek and creating vegetated land buffers between areas of mudboil activity along with capturing mudboil discharges at the source in an impoundment or constructed wetland should cause upstream waters to bypass the MDA and RMA, such that downstream water quality would essentially equal that of upstream, in addition to capturing mudboil sediment and saline discharges on-site. A salt-marsh could be established to treat saline waters released from mature mudboils.

I. Efficacy - potential effectiveness: HIGH

II. Environmental compatibility: Creating a new naturalized creek and wetland retention system would be **highly compatible** with the surrounding environment.

IV. Technical Implementability: The proven state of the science of creek relocation and the already demonstrated means of at-source settling via impoundment and wetland creation suggests that this combination of actions is highly favorable form a technical implementability aspect; yet, consideration of the environmental uncertainties and risks, suggests that this action be lowered to a **moderate technical implementability**. The farther the distance between the relocated stream bed and the old streambed, historic (MDA) and active mudboils (RMA) and land subsidence, the less likely the future occurrence at the new creekbed location. Further, the greater the area to construct at-source settling in the form of an earth dam basin and/or constructed wetland. Still the influence of newly situated surface water bodies and their relationship to ground water as pertaining to the potential to cause mudboil activity would need to be evaluated[27].

V. Permanence: The permanence of this combination of actions is considered **high** due to the ability to capture and mitigate mudboil discharges at the source and simultaneously transfer upstream waters to a downstream location free of mudboil influence. This statement is tempered with an understanding that geography and land use may limit the distance the creek can be moved from the mudboils.

VI. Adaptability: As presented in the summary matrix (Table 8), by moving the creek a significant distance from known areas of mudboil activity and capturing mudboil discharges on-site are considered adaptable with respect to changing site conditions. The potential for mudboil activity to occur subsequent to remedial efforts or other forms of human intervention is eminently probable based on historical incidence (refer to page 6, *Uncertainty Discussion*). Nevertheless, because both creek relocation and at-source settling actions are repeatable, the potential exists that subsequent similar measures could be implemented or modified at differing and multiple locations in response to future mudboil activity. Both actions are reversible as any structure to impound mudboil discharges could be removed, if practical, and creek flow can be returned to the historical stream channel. Thus, these combined actions are considered to have **high adaptability.**

Table 8 shows the contrast in selection criteria rankings between Potential Action 3: Creek Relocation as a standalone project versus that performed together with Potential Action 2: At-source settling.

Table 8. Screening matrix for Creek Relocation/At-source Settling.

	Creek Relocation	Creek Relocation w/At-source Settling
I. Effectiveness	🟢	🟢
II. Environmental compatibility	🟢	🟢
IV. Technical Implementability	🟡	🟡
V. Permanence	🔴	🟢
VI. Adaptability	🟡	🟢

[27] As previously stated, creek and watershed manipulations have not been applied as a solution to mudboil activity, as mudboils do not exist elsewhere. No information was located in the available literature pertaining to the occurrence of cool ground water vents under artesian pressure. Likewise, no information was located in the available literature regarding stream restorations in similarly unstable substrates. Nevertheless, inherent risks associated with instability of the valley floor and the potential for mudboil activity and land subsidence to follow the creek relocation need to be examined should this potential action be recommended for FS.

Potential Action 4: At-source flow diversion with Potential Action 2: At-source settling

The following work elements would be performed in combination.

4. At-source water flow (Q) diversion from MDA

A. Actual MDA Q
   1. Similar to directional drill project
   2. Could be located as identified in TVGT report

B. Q into MDA
   3. Redirect flow that is entering MDA/analogous to 1993 tributary relocation to the south
   4. Reduce the size of drainage basin (subwatershed entering MDA)
   5. Reduce volume of water flowing through active RMA

2. At-Source Settling (e.g., Basin at Rogue MB [Soft])

A. Demonstration project
B. Dam of variable size (could be inflatable)
C. Impounded water causes settling at the source
D. Limit/minimize runoff into Rogue area (see Potential Supplemental Action 7)

This combination of potential actions is similar to those implemented in 1993 with source water diversion control and at-source settling. Together these actions would redirect source water entering active mudboil areas from the surrounding drainage basin to reduce the volume of water while capturing and settling mudboil discharges on-site. By eliminating or greatly reducing source water to areas of mudboil activity, the source of sedimentation to Onondaga Creek can be mitigated in a more concentrated form via an at-source earth dam impoundment and/or constructed wetland. Both these remedial actions would require on-going monitoring and maintenance. Combining source water diversion with at source settling can be highly effective. Yet, because this combination of potential actions does not address mudboil activity in the creek, the effectiveness is considered moderate.

I. Efficacy - potential effectiveness: MODERATE

II. Environmental compatibility: The potential action of source water diversion would be visually unobtrusive and is highly compatible with the surrounding environment; however, the potential action of constructing an earth dam and impoundment along with the need to dredge and manage accumulated sediments at the source, causes this combination of potential actions to be ranked as **moderately** compatible with the surrounding environment.

IV. Technical Implementability: As noted above, both technologies have been applied previously and have a **high technical implementability**.

V. Permanence: If properly maintained, both potential actions are considered to have **high permanence** with respect to known areas of mudboil activity targeted by this action. As noted, in the absence of proper maintenance, natural systems can re-establish old flow patterns and new mudboil activity may occur.

VI. Adaptability: This combination alternative is considered to have **moderate adaptability**, possibly adaptable to the occurrence of new mudboils depending on the location. Mudboils that occur within the existing creek bed, for example, would not be practical to address using this alternative. The efficacy of this potential action would be low should a mudboil break out, as in the past, within Onondaga Creek. Further, the potential for mudboil activity to occur subsequent to remedial efforts or other forms of human intervention is eminently probable based on historical incidence (see uncertainty discussion on page 6). Both actions are reversible.

Table 9 shows the contrast in selection criteria rankings between Potential Action 4: At-source flow diversion as a standalone project versus that performed together with Potential Action 2: At-source settling.

Table 9. Screening matrix for Source Water Diversion/At-source Settling.

	Source Water Diversion	Source Water Diversion w/At-source Settling
I. Effectiveness	🟡	🟡
II. Environmental compatibility	🟢	🟡
IV. Technical Implementability	🟢	🟢
V. Permanence	🟢	🟢
VI. Adaptability	🟡	🟡

Potential Action 5: Inline settling with Potential Action 2: At-source settling

The following work elements would be performed in combination.

5. Inline Downstream Settling (Downstream of Mudboil Activity)

A. Create settling impoundment/reservoir
B. Reservoir could cover active mudboil areas
  6. Could cover rogue
  7. Could cover MDA
  8. Could cover both
C. Could be a series of dams/reservoirs capturing Onondaga Creek (EMM's conceptual drawings from 9/14/18: #s 1 & 2)
D. This option becomes Potential Action II if Potential Action V is implemented and Onondaga Creek is relocated
E. Reservoirs would warm the water
F. Preference would be to have settling occur off-line

2. **At-Source Settling (e.g., Basin at Rogue MB [Soft])**
   A. Demonstration project
   B. Dam of variable size (could be inflatable)
   C. Impounded water causes settling at the source
   D. Limit/minimize runoff into Rogue area (see Potential Supplemental Action 7)

This combination of potential actions involves the creation of two or more settling impoundments/reservoirs by damming Onondaga Creek both at the mudboil source area and downstream of known mudboil activity. Just as with Potential Action 2: At-Source Settling[28], earth dams would be the preferred structure. Depending on size and scale of the containment areas, these successive potential actions have the potential to be highly effective under base flow and possibly high flow conditions.

I. Efficacy - potential effectiveness: HIGH

This action involves creation of two or more reservoirs/impoundments which are considered aesthetically compatible with the general surroundings. A series of low head dam structures that create a string of shallow wetlands could be developed from the mudboil source area and extend northward throughout the valley and well beyond historic mudboil activity. Yet the potential for mudboil activity to occur subsequent to remedial efforts or other forms of human intervention is eminently probable based on historical incidence. The placement of dams further to the north may avoid historic mudboil activity; however, land ownership and infrastructure issues could make siting more difficult.

II. Environmental compatibility: This combination of potential actions is considered to have **moderate environmental compatibility**; a major reason would be the increase in water temperature impounded behind dams, thereby causing a downstream warming effect via the discharge of lentic water into a lotic system. Ponding of flowing waters results in the warming of those waters which is ecologically incompatible with a creek in which a goal exists for trout restoration. Still a naturalized wetland or system of wetlands can be constructed to induce settling, but also provide flood storage and habitat, spawning and nursery grounds for fish and wildlife. A salt marsh community could be established on-site to mitigate saline discharges associated with mature mudboils.

IV. Technical Implementability: Sedimentation basins are a common mitigation technique, although usually at a lesser scale than what is proposed herein, thus this technology is considered to have **moderate technical implementability** due to the necessary size requirements needed to control large volumes of water in order to obtain proper settling, dam safety hazards, and the complexity of design. Yet, a low head or series of low head wetland basins might be achievable for base flow conditions. A series of wetlands may necessitate the bypass of high flow events.

V. Permanence: If properly maintained, this potential action is considered to have **high permanence**.

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[28] Should the dam structure impound Onondaga Creek flow under Potential Action 2: At Source Settling, then Potential Action 5: Downstream Inline Settling is the same except for location.

VI. Adaptability: This combination of actions would address sedimentation from existing, known areas of mudboil activity and would also address future occurrences of mudboils, if occurring within the generally recognized areas where mudboils might occur and thus this combination is considered to have **high adaptability**. This action is reversible as any damming structure can be removed and creek flow can be returned to the historical stream channel.

Table 10 shows the contrast in selection criteria rankings between Potential Action 5: Inline settling as a standalone project versus that performed together with Potential Action 2: At-source settling.

Table 10. Screening matrix for Source Water Diversion/At-source Settling.

	Inline Downstream Settling	Inline Downstream Settling w/At-source Settling
I. Effectiveness	● (green)	● (green)
II. Environmental compatibility	● (yellow)	● (yellow)
IV. Technical Implementability	● (red)	● (yellow)
V. Permanence	● (green)	● (green)
VI. Adaptability	● (green)	● (green)

Comparison of Potential Action Combinations:

Table 11 contrasts the remaining selection criteria of **effectiveness**, **environmental compatibility, technical implementability**, **permanence**, and **adaptability** against the five combinations of potential and supplemental actions. Hereafter, combinations are referred to as alternatives[29]:

Alternative 1: Potential Action 1: Offline settling with Supplemental Action: post-settling polishing wetland,
Alternative 2: Potential Action 2: At-source settling with Supplemental Action: post-settling polishing wetland,
Alternative 3: Potential Action 3: Physical separation (Creek relocation) with Potential Action 2: At-source settling,
Alternative 4: Potential Action 4: At-source flow diversion with Potential Action 2: At-source settling, and
Alternative 5: Potential Action 5: Inline settling with Potential Action 2: At-source settling.

[29] The TAG defined the 5 potential and supplemental action combinations as corresponding alternatives 1 through 5.

Table 11. Screening Analysis for Action Combinations.

Alternative	1	2	3	4	5
	Potential Action 1: Offline settling with Supplemental Action: post-settling polishing wetland	Potential Action 2: At-source settling (at Rogue mudboil) with Supplemental Action: polishing wetland	Potential Action 3: Physical separation (Creek relocation) with Potential Action 2: at-source settling	Potential Action 4: divert flow from MDA with Potential Action 2: At-source settling	Potential Action 5: Inline settling (reservoir at Onondaga Creek) with Potential Action 2: at-source settling
I. Effectiveness	● (yellow)	● (yellow)	● (green)	● (yellow)	● (green)
II. Environmental compatibility	● (yellow)	● (yellow)	● (green)	● (yellow)	● (yellow)
IV. Technical Implementability	● (green)	● (green)	● (yellow)	● (green)	● (yellow)
V. Permanence	● (green)	● (green)	● (green)	● (green)	● (green)
VI. Adaptability	● (green)	● (yellow)	● (green)	● (yellow)	● (green)

Note: Potential Actions 1 & 2 were supplemented with a polishing wetland
Potential Actions 3, 4, & 5 were combined with Potential Action 2: At-source settling

None of the combinations ranked in the less favorable category for any of the remaining selection criteria. All combinations scored at least two selection criteria with two or more highly favorable rankings. Combinations with two highly favorable rankings and three moderately favorable rankings included:

Alternative 2: At-source settling with post-settling polishing wetland
Alternative 4: At-source flow diversion with at-source settling

Combinations with three highly favorable rankings and two moderately favorable rankings included:

Alternative 1: Offline settling with post-settling polishing wetland
Alternative 5: Inline settling with at-source settling

Only **Alternative 3** (Physical separation [Creek relocation] with at-source settling) had four highly favorable rankings and one moderately favorable ranking (technical implementability). Likewise, this combination was the only to rank highly favorable with environmental compatibility. **Alternative 5**

(Inline settling with at-source settling) was the only combination besides **Alternative 3** (Physical separation [Creek relocation] with at-source settling) to rank highly favorable for effectiveness. Based on the professional judgment of the DT, the combination of potential actions of physical separation and at-source settling at mudboils area (Alternative 3) appears to provide the optimum performance relative to the metrics of immediate **effectiveness**, **environmental compatibility, technical implementability**, **permanence**, and **adaptability**.

C. Alternatives Recommendation for Feasibility Study

A total of three alternatives (combinations of potential actions) were recommended for FS.

The TAG met on June 21, 2019 and selected:

Alternative 1: Offline settling with a post-settling polishing wetland,
Alternative 3: Physical separation (Creek relocation) with at-source settling, and
Alternative 5: Inline settling with at-source settling.

A significant effort would be put forward in attempting to identify the scientific uncertainty and possible risks associated with implementation of each alternative. All alternatives will be evaluated against a no-action scenario, which could be the recommended FS outcome.