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Pilot Study Work Plan
Former Circle K Site

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Prepared for

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Section 1: Introduction and Pilot Study Summary

This work plan summarizes the approach and activities that will be performed as part of a field pilot study at the Former Circle K (Circle K) site located at 2350 24th Avenue East in Seattle, Washington. This work is being performed on behalf of the Washington State Department of Ecology (Ecology).

The proposed *in situ* Pilot Study (pilot study) includes a surfactant flushing step (injection/extraction and extended extraction period) followed by the injection of biological amendments through a manually-controlled short-term (7-day) groundwater recirculation event. The purpose of the pilot study is to assess whether or not *in situ* bioremediation may be a viable remedial technology for the site.

The proposed pilot study for the Circle K site will consist of three main work phases, including:

1. Installation and development of injection/extraction wells (multi-purpose wells).
2. Performance of the field activities associated with the pilot study.
3. Post pilot study groundwater monitoring to evaluate its effectiveness.

It is anticipated that the work associated with Phases 1 and 2 will be completed before 31 May 2017. Phase 3 (post pilot study groundwater monitoring) will be performed at a future date when there is available funding by Ecology.

1.1 Pilot Study Summary

Initially, a low-concentration surfactant solution will be injected into the impacted groundwater zone through the injection wells and removed using groundwater extraction wells. The process of injection combined with extraction is referred to as recirculation system and will be performed for approximate 2 to 3 days. As the surfactant solution migrates from the injection wells to the extraction wells, hydrocarbon is desorbed from the soil matrix, mobilized for hydraulic capture, pumped to an onsite holding tank, and transported offsite for disposal. In general, the target removal volume is typically equal to 1.5 to 2.0 times the surfactant solution injection volume in order to capture as much of the mobilized hydrocarbon as possible. To accomplish this, the extraction period will likely extend beyond the injection period by up to 2 days longer that the recirculation step. Some surfactant solution will still remain in the treatment zone after the extraction phase is completed, which will be used to enhance the bioremediation phase of the process (surfactant-enhanced bioremediation).

Following completion of the surfactant injection/extraction step, biological amendments (consisting of macronutrients and a cultured bacteria consortium) will be injected to the affected areas using the recirculation system described above. The goal of this step will be to distribute depleted macronutrients and bacteria to the most heavily impacted areas. This final step of the pilot study will last for approximately 2 days.

Section 2: Overview of the Bioremediation Process

Bioremediation involves bioaugmentation (i.e., addition of specific microorganisms) and/or stimulation of petroleum-degrading bacteria to mineralize the petroleum hydrocarbon compounds (i.e., convert them to carbon dioxide and water). In addition, this process typically requires adding now-depleted macronutrients (nitrogen as ammonia and phosphorous as phosphate), terminal electron acceptors (TEAs) for microbial respiration [i.e., dissolved oxygen (DO), nitrate, etc.], and, if warranted, bacteria that are selectively cultured for their petroleum-degrading capabilities (e.g., facultative petroleum hydrocarbon-degrading bacteria).

Bioamendments (i.e., TEAs, bacteria, and macronutrients) will be added after application of the dilute surfactant solution using the same groundwater recirculation methods described above. Once the initial DO from the breakdown of the surfactant solution is utilized (via aerobic biodegradation), the “facultative” bacteria will also be able to “breath” with nitrate instead of DO (anaerobic biodegradation, nitrate-reducing conditions). While oxygen-respiration yields the fastest bioremediation, the maximum concentrations of oxygen typically achievable in groundwater limits the duration of this phase, or requires re-addition of oxygen. These three processes – initial surfactant flushing, bioremediation using residual oxygen respiration, and bioremediation using prolonged nitrate respiration – are integral to the sustained bioremediation.

The depletion of TEAs and macronutrients causes the microbial kinetic rates/growth to decrease by orders of magnitude, inhibiting the biodegradation of contaminants. Consequently, augmentation of the TEAs and macronutrients is necessary to maintain ongoing bioremediation. The dilute surfactant circulated during the initial part of the pilot study will generate a moderate concentration of DO. However, this DO half-life will be very short (days to weeks) due to the high biochemical oxygen demand/chemical oxygen demand (BOD/COD) mass balance. Therefore, other TEAs will be required to maintain robust microbial activity.

Nitrate is the second most energetically favorable TEA for bacteria to utilize, and it has a high solubility limit allowing a larger mass to be injected into the target zone. The injection of nitrate will provide the additional TEA mass required to overcome the mass balance requirement to achieve low level remedial goals. Ammonia and phosphorous will also need to be added to prevent nutrient-limited kinetic rates from occurring. The generally accepted ratio of carbon to nitrogen to phosphorous is 100:10:1. This ratio indicates a significant mass of ammonia (and a less significant mass of phosphorous) needs to be added along with the nitrate in order to maximize the effectiveness of the approach.

In addition, the bioaugmentation process will include injection of a microbial consortium of facultative petroleum-hydrocarbon-degrading bacteria. As DO and nitrate are the primary TEAs, facultative bacteria should be introduced to augment the subsurface with the correct consortium of bacteria to prevent microbial lag phases due to the dramatic shift in redox conditions [and oxidation-reduction potential (ORP)].

There will also be residual surfactant solution remaining in the target zone (<1 percent) to help increase the bioavailability of the highly-adsorbed contaminants. Increased bioavailability of the adsorbed contaminant mass in the presence of TEAs and micronutrients will help maximize the effectiveness of the remedial approach.

Section 3: Groundwater Recirculation Delivery Method and Proposed New Well Installation

Both the surfactant flushing and bioremediation phases of this process require contact of the surfactants and amendments to be effective. By actively extracting groundwater from wells while injecting into other multi-purpose wells, artificial hydraulic groundwater gradients will be temporarily created that will help facilitate distribution and contact in the subsurface petroleum-affected soils.

The chemical/biological amendments require distribution in the impacted subsurface to achieve contact with the contaminated media (soils and groundwater). Without contact/distribution through recirculation, the remedial approach will not be as effective is could be. For this pilot study, contact of surfactant and amendments will be performed using a network of new and existing site wells. Currently, there are two existing 4-inch wells (MW-20 and MW-21) that can be used for this pilot study. In addition, up to seven additional 4-inch wells are proposed. The new 4-inch multi-purpose wells (RW-1 through RW-7) can be used for injection and extraction purposes during the pilot study (refer to Figure 1).

If the pilot study indicates that the remedial process is successful, these same wells can be used in the future for manual groundwater recirculation events. Typically, these events could be repeated every 3 to 18 months (as needed) until cleanup standards are achieved. It is typically preferable to conduct these events as close the seasonal high groundwater elevation timeframe (i.e., late fall through spring) in order to obtain more complete contact with the smear zone.

Section 4: Bioremediation Equipment, Products, and Infrastructure Specifications

4.1 Trailer-Mounted Recirculation System, Piping and Equipment

For this pilot study, we propose to extract groundwater and inject amendment solutions using a portable, trailer-mounted system supplied by Etec Environmental Technologies (Etec) located in Washougal, Washington. Use of the trailer-mounted system will allow use of the aboveground hose, eliminating the need to trench and install permanent piping between the wells and system.

Etec will mobilize a truck/trailer-mounted injection system consisting of a large poly tanks (holding tank, and two post-treatment/mixing tanks), injection/transfer pumps [15 to 20 gallon per minute (gpm) capacity], re-circulation and injection lines, granular activated carbon (GAC) vessel/fittings, valves/fittings, flow meters, pressure gauges, submersible extraction pumps, and other ancillary equipment. A generator will also be supplied to power the injection and extraction pumps. Etec will have an injection header that has six stations, each with its own flow meter, pressure gauge, and gate valve for independent flow control.

For safety reasons, Etec will provide a minimum of two employees to conduct the work. Etec will need a potable water source onsite to complete their work.

During performance of the pilot study, Etec will use cones, caution tape, and barricades to control vehicle and foot traffic to the work areas. Attempts will be made to reduce the footprint of the work area so there is the least impact on the site business.

4.2 Remediation Products

The proposed surfactant injection approach will utilize Etec's non-ionic surfactant, PetroSolv™. PetroSolv™ is a naturally-formulated, non-toxic, biodegradable, non-ionic surfactant designed for temporary emulsification of hydrophobic constituents (like petroleum compounds). The PetroSolv™ product has been used successfully on many gasoline-, diesel-, and heating oil-impacted sites around the country.

Analytical laboratory results from various surfactant studies have shown that non-ionic surfactant solutions at concentrations ranging from 0.1 to 10.0 percent can effectively provide emulsification and mobilization of hydrocarbon constituents. However, PetroSolv™ application rates are also a function of the impacted soil volume being treated. Using Etec's general application guideline based on *ex situ* and *in situ* field experience, which estimates that 1 gallon of concentrated PetroSolv™ is typically appropriate for application to 2 to 5 cubic yard (CY) of soil volume, then a single injection/extraction event would require 110 to 275 gallons of PetroSolv™. For this injection/extraction pilot study, we recommend application of **150 gallons of PetroSolv™**.

For the bioremediation amendments, we recommend using Etec's TPH Bacterial Consortium (EZT-A2), a facultative microbial consortium. Etec's Custom Blended Nutrients (CBN) nutrients, which include macro- and micro-nutrients specially blended for *in situ* bioremediation, is also recommended due to the high weight percent of nitrate, ammonia, and phosphate in that product. These biological enhancements work together to efficiently degrade gasoline-range hydrocarbons; benzene, toluene, ethylbenzene, and total xylenes (BTEX); naphthalenes; and other organic contaminants.

The application of the biological products will perform three critical functions, including:

1. Supply of a large population of pre-acclimated facultative bacteria to optimize initial growth of a healthy, *in situ*, hydrocarbon-degrading microbial population.

2. Maximize contact between the contaminants (dissolved and adsorbed) and the bacteria. Effective bioremediation relies on physical contact with the hydrocarbon food source and the electron acceptors (oxygen, nitrate, sulfate) to biochemically oxidize the contaminants to carbon dioxide (CO_2) and water.

3. Supplying critical nutrients like nitrogen, phosphorus, and potassium help support ongoing biological growth. The nitrogen compounds also act as secondary electron acceptors to ensure continuous *in situ* contaminant degradation during temporary absences of oxygen.

Section 5: Surfactant/Bio-Recirculation Treatment Pilot Study Events

Following installation of the pilot study multi-purpose wells, the pilot study will consist of three separate steps consisting of:

- Step 1: Surfactant injection, for 2 to 3 days, followed immediately by
- Step 2: Groundwater extraction and disposal for 2 to 3 days
- Step 3: Biological amendment recirculation for up to 2 days.

5.1 Step 1 – Surfactant Injection – 2 to 3 Days

During Step 1, Etec will initially inject up to 5,000 gallons of dilute liquid surfactant (3 percent solution) into the impacted soil/groundwater zone over a period of approximately 2 to 3 days. Up to five multi-purpose wells will be used for the injection process in the most affected part of the hydrocarbon plume. By injecting the solution under pressure [10 to 20 pounds per square inch (psi)], we can increase the radius of influence (ROI) around each well within the target zone and enhance the effectiveness and contact area for the surfactant solution.

Concurrently with injections, we will extract from up to four multi-purpose wells to create a cone of depression, further increasing the ROI. If warranted, the set up gives us the flexibility to switch one or more injection wells to extraction use to increase overall pilot study flexibility. The extracted groundwater (emulsified oil and water mixture) will be temporarily contained in an onsite storage tank for offsite disposal.

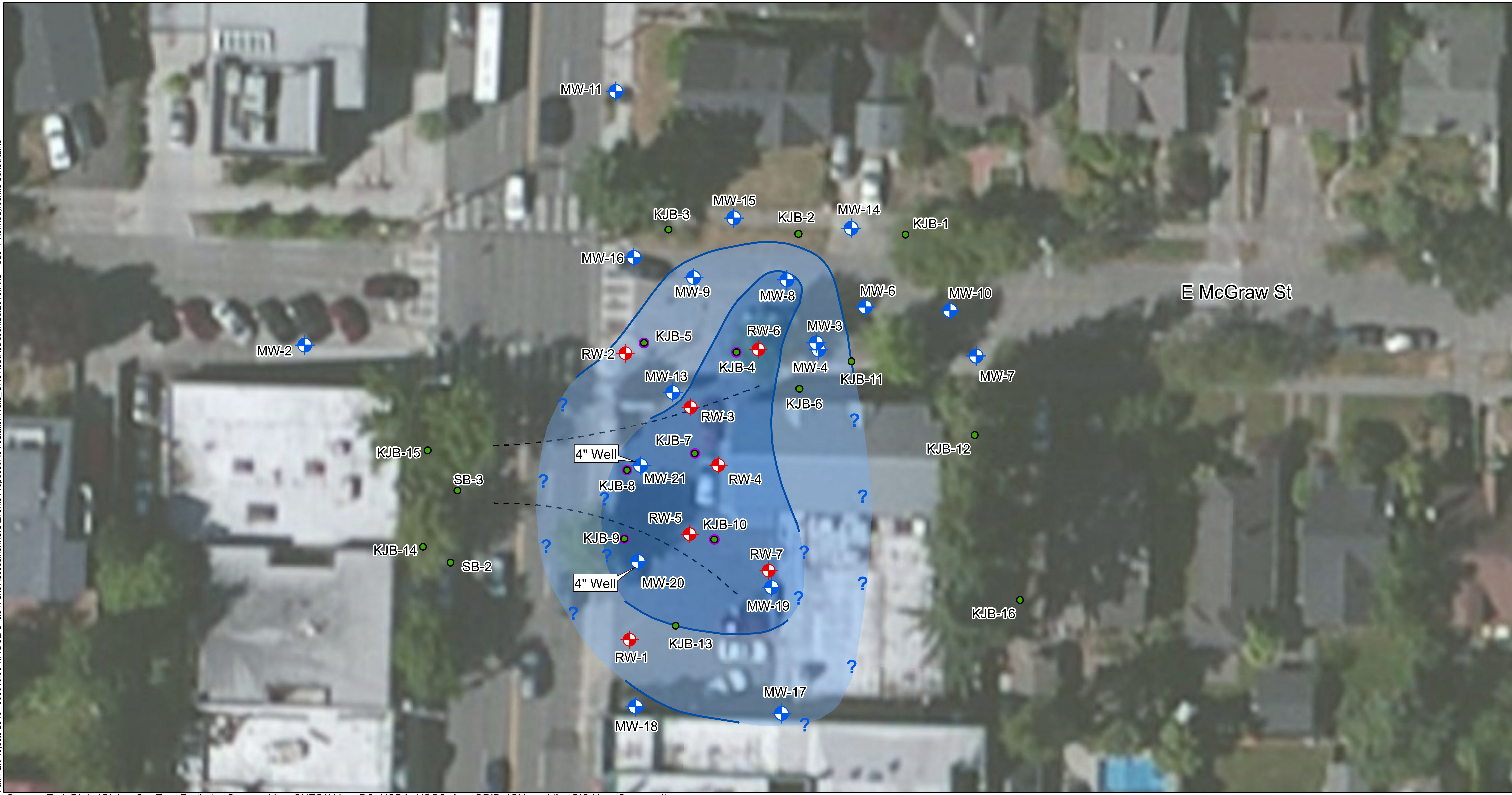
5.2 Step 2 – Groundwater Extraction of Surfactant Solution – 2 to 3 Days

Following the surfactant injection phase, the groundwater extraction phase will commence immediately or the following morning. A vac truck will be used to pump out the holding tanks containing the extracted groundwater surfactant solution (i.e., emulsion). We anticipate extracting and disposing of up to 7,500 gallons of groundwater solution over 2 to 3 days. Etec will be monitoring the extracted groundwater for indications that the majority of surfactant has been removed.

5.3 Step 3 – Biological Amendment Injection – 2 Days

Following the surfactant removal phase, the recommended biological amendments will be mixed in aboveground tanks and injected into the target wells over a 2-day period. The addition of bacteria, substrates, and biological nutrients will support microbial degradation of residual petroleum constituents and partially-oxidized petroleum intermediates that are contacted by the recirculated flow and bacteria. Approximately 1,000 pounds of CBN nutrients and 15 gallons of bacteria would be mixed with approximately 3,000 gallons of water and injected into the multi-purpose wells. Etec will monitor extracted groundwater for water quality parameter shifts [pH, electrical conductivity (EC), ORP, and DO] to evaluate breakthrough of the bioamendments to extraction well locations.

Figure



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Legend

- Proposed New Remediation Well
- Monitoring Wells
- Soil Borings
- Soil Boring Location with Gasoline-Range Hydrocarbons above the MTCA Method A Cleanup Level for Soil
- Estimated Gasoline-Range Hydrocarbon Isoconcentration (>1,000 µg/L)
- Estimated Gasoline-Range Hydrocarbon Isoconcentration (>50,000 µg/L)
- Possible Future Horizontal Well

Note:
1. All locations are approximate.
2. This drawing is for information purposes. It is intended to assist in showing features discussed in an attached document.
3. µg/L = micrograms per liter.

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0 20 40

Scale: Feet

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Former Circle K Site
Seattle, Washington

Estimated Groundwater Gasoline-Range Hydrocarbon Isoconcentrations December 2016

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Figure 1