

IDENTIFICATION OF ILLICIT CONNECTIONS IN STORM SEWERS: AN INNOVATIVE APPROACH USING STABLE ISOTOPES

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ABSTRACT

Illicit connections from domestic, commercial, and industrial sources to storm sewers create pollution of receiving water, and must be identified and eliminated. Traditional approaches for identifying illicit connections use physical tests, such as dye and smoke testing, and chemical analyses of water. These approaches may be either prohibitively expensive for use in large areas or may not always result in clear identification of illicit connections. An innovative approach to identifying illicit connections is based on the analyses of naturally occurring stable isotopes of oxygen and hydrogen. We conducted a feasibility study for the Rouge River National Wet Weather Demonstration Project to evaluate the applicability of the stable isotope approach to identify illicit connections in three mini watersheds in or near Wayne County, Michigan. The study areas included residential and industrial areas where illicit connections are known to be present or are considered to have been eliminated by traditional testing. Isotopic signatures of local groundwater, sanitary sewer water, and tap water were significantly different. In all cases, the isotopic results based on 2-6 samples from a given sewer system were sufficient to characterize the source of flow (groundwater, rain water/snow melt, or sanitary flow) in the storm sewers. In one area where all known illicit connections from industrial sources had been eliminated using smoke and dye testing, the isotopic approach identified the existence of illicit connections in one portion of the sewer system. Our results indicate that the isotopic technique is extremely cost-effective and robust for distinguishing between local groundwater and water derived from domestic and industrial or commercial sources, and thus allows determination of the existence of illicit connections or precludes their existence. If illicit connections are identified, the isotopic approach may be used to isolate a very limited area for further testing to identify the source of illicit discharge.

Keywords Illicit Connections, Stable Isotopes, Storm Sewers

INTRODUCTION

Illicit connections from domestic, commercial, and industrial sources to storm sewers create pollution of receiving water, and must be identified and eliminated. Urban stormwater drainage systems are designed to carry flows resulting from surface runoff of precipitation. Traditional approaches for identifying the sources of dry-weather flow or base flow in storm sewers use physical means of testing, such as tracer and pressure tests, and chemical analyses of water. The physical testing methods, however, can be prohibitively expensive for use in large areas or in areas where multiple sources of illicit connections may exist. The chemical methods may not always result in clear identification of sources, because chemical compositions may change naturally as a result of geochemical reactions or may not be sufficiently discriminating between the various sources.

Investigations to determine the source of base flow in storm sewers would be extremely cost-effective if it could be quickly determined whether the base flow results from leakage of shallow groundwater or from illicit connections. An ideal tracer for distinguishing between groundwater and other sources of flow as well as identifying the source of illicit connections should be naturally present in the different sources of water to storm sewers (rainwater, groundwater, domestic and industrial discharge, or

sanitary sewer discharge). In addition, the tracer should either not change its characteristics during transport in the storm sewer system or change along a predictable path.

An abundance of naturally occurring stable (non-radioactive) isotopes of oxygen and hydrogen provide an effective and robust means of distinguishing between local groundwater and water derived from other sources. The usefulness of the stable isotope analyses stems from the fact that these isotopic compositions are characteristic of the origin of water and/or solutes. Consequently, the isotopic compositions may allow the development of a "fingerprint" of different sources of discharge in a given area. These "fingerprints" may then be used to identify the source (groundwater or illicit connections) of dry weather flow in a storm sewer.

As part of the Rouge River National Wet Weather Demonstration Project, we conducted a feasibility study to evaluate the use of the stable isotope approach for illicit discharge identification in the Rouge River Watershed (Figure 1). Results of this investigation are presented in this paper. The paper briefly discusses the theoretical background of stable isotope geochemistry and then describes the results of the study. The stable isotopic compositions are frequently used in surface or groundwater hydrology to determine the origin and subsequent history of natural waters. To the best of our knowledge, the isotopic technique has not been previously used for the investigation of illicit discharge to storm sewers.

STABLE ISOTOPE GEOCHEMISTRY OF NATURAL WATERS

There are two stable isotopes each of hydrogen (^1H or H and ^2H or D) and oxygen (^{18}O and ^{16}O) which are useful for tracing the origin of waters. The stable isotopic compositions are conventionally reported as parts per thousand (per mil) deviation from an arbitrary standard using the delta notation:

$$\delta i = (R_x/R_{\text{std}} - 1) 1000 \quad (1)$$

where i is ^{18}O or D , and R is the ratio of heavy to light isotopes (D/H or $^{18}\text{O}/^{16}\text{O}$) in a sample (x) or the standard (std). The isotopic standard is SMOW (Standard Mean Ocean Water) (Craig, 1961a). Oxygen and hydrogen isotope ratios in atmospheric precipitation (rain and snow) are characteristic of geographic location and climatic conditions. The following relationship has been established for the stable oxygen and hydrogen isotopic ratios in rain and snow on a global scale (Craig, 1961a):

$$\delta\text{D} = A \delta^{18}\text{O} + B \quad (2)$$

If $\delta^{18}\text{O}$ is plotted against δD , the line representing the above equation is known as the "global meteoric water line" (MWL). The values of A and B in Equation 2 average 8 and 10, respectively, on a global basis (Craig, 1961b; Dansgaard, 1964), although deviations from these values may occur on a local scale.

Figure 2 shows the expected relationship of isotopic compositions of surface and groundwaters in a small watershed. There are significant seasonal variations in the oxygen and hydrogen isotopic compositions of rain and snow at a given location, although they all plot along the MWL. The summer precipitation has higher (less negative) $\delta^{18}\text{O}$ and δD values compared with winter precipitation. Most groundwaters originate by downward percolation of surface waters. Oxygen and hydrogen isotopic compositions of shallow groundwaters in temperate climates such as in Michigan generally are very nearly the same as the mean annual composition of surface precipitation, in spite of the large variations in the isotopic composition of precipitation. Selective recharge, physical mixing, and transpiration in the root zone all tend to homogenize the isotope compositions of recharge waters within a few feet of downward percolation.

Evaporation of rainwater, such as in lakes or ponds or during infiltration in the shallow subsurface, results in the enrichment of the heavier isotopes in the residual fraction. Partially evaporated natural waters that originated as rain or snow plot to the right of the MWL.

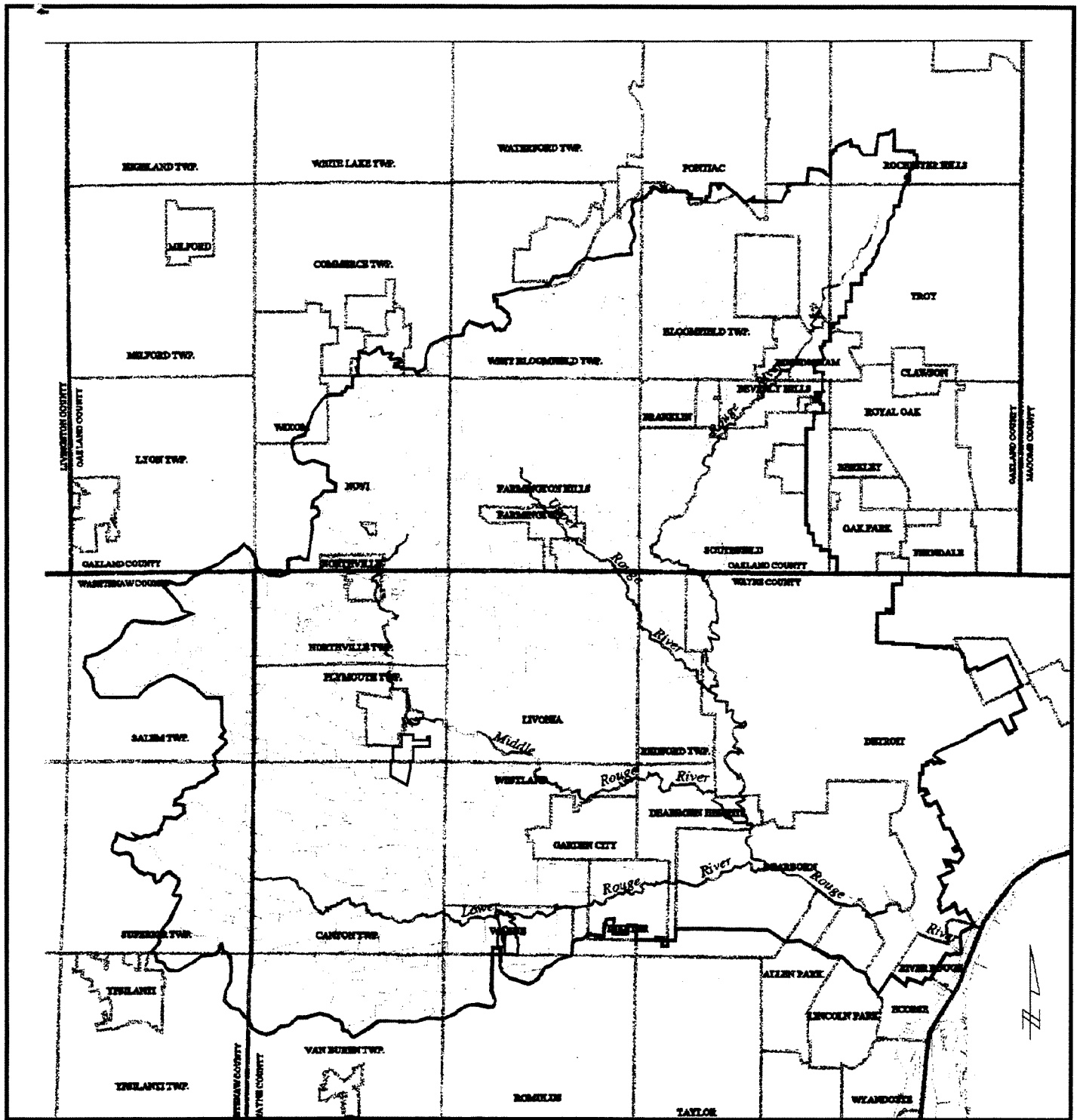


Figure 1. Rouge River Watershed

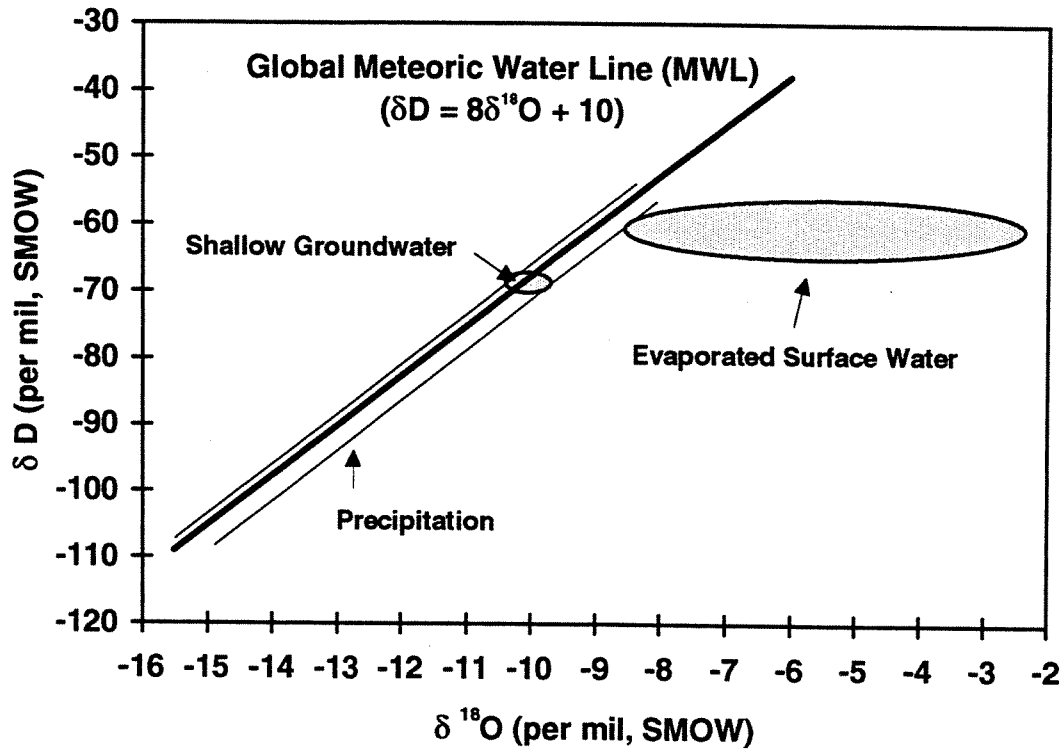
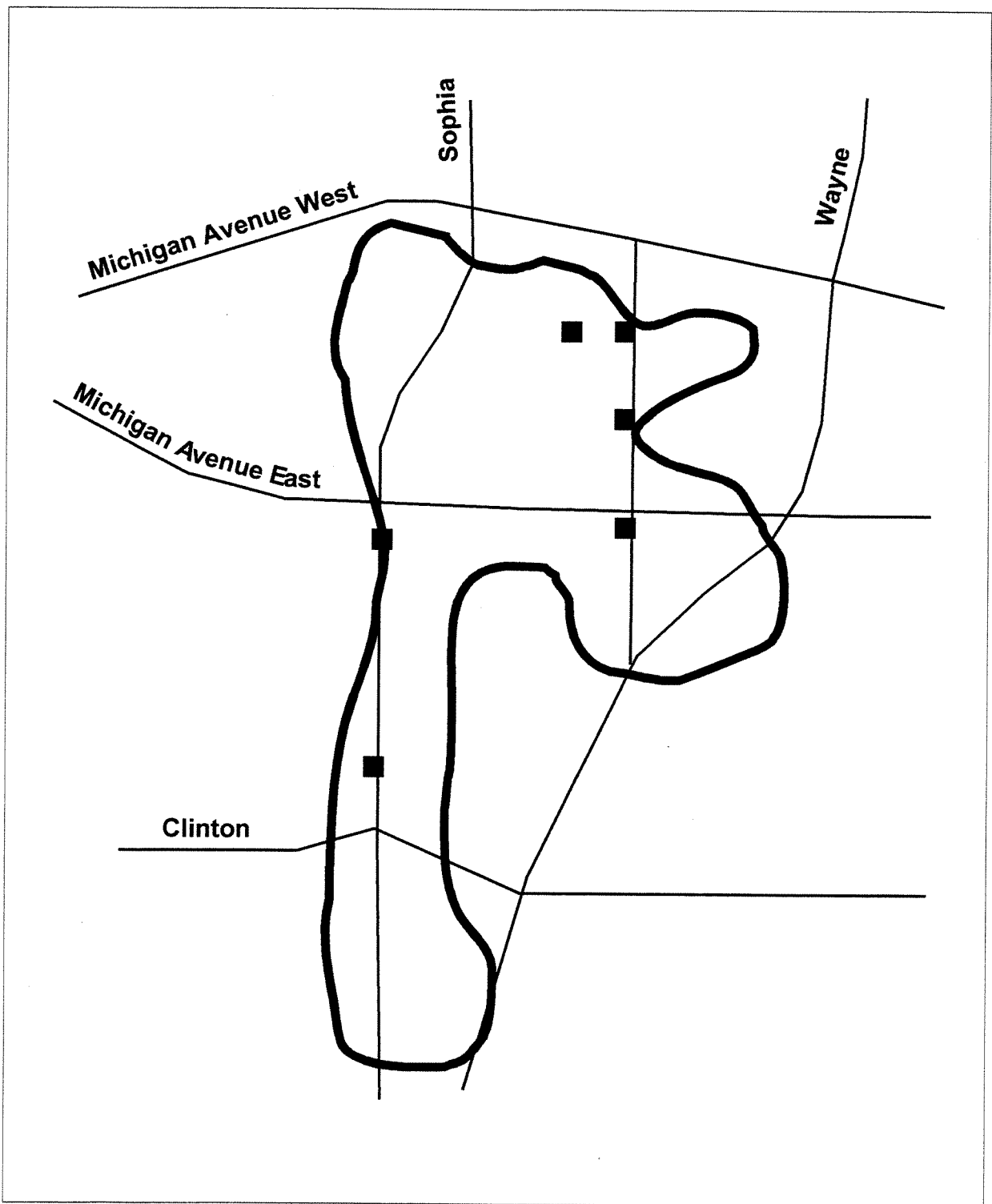


Figure 2. Expected Stable Isotope Relationships in Natural Waters.

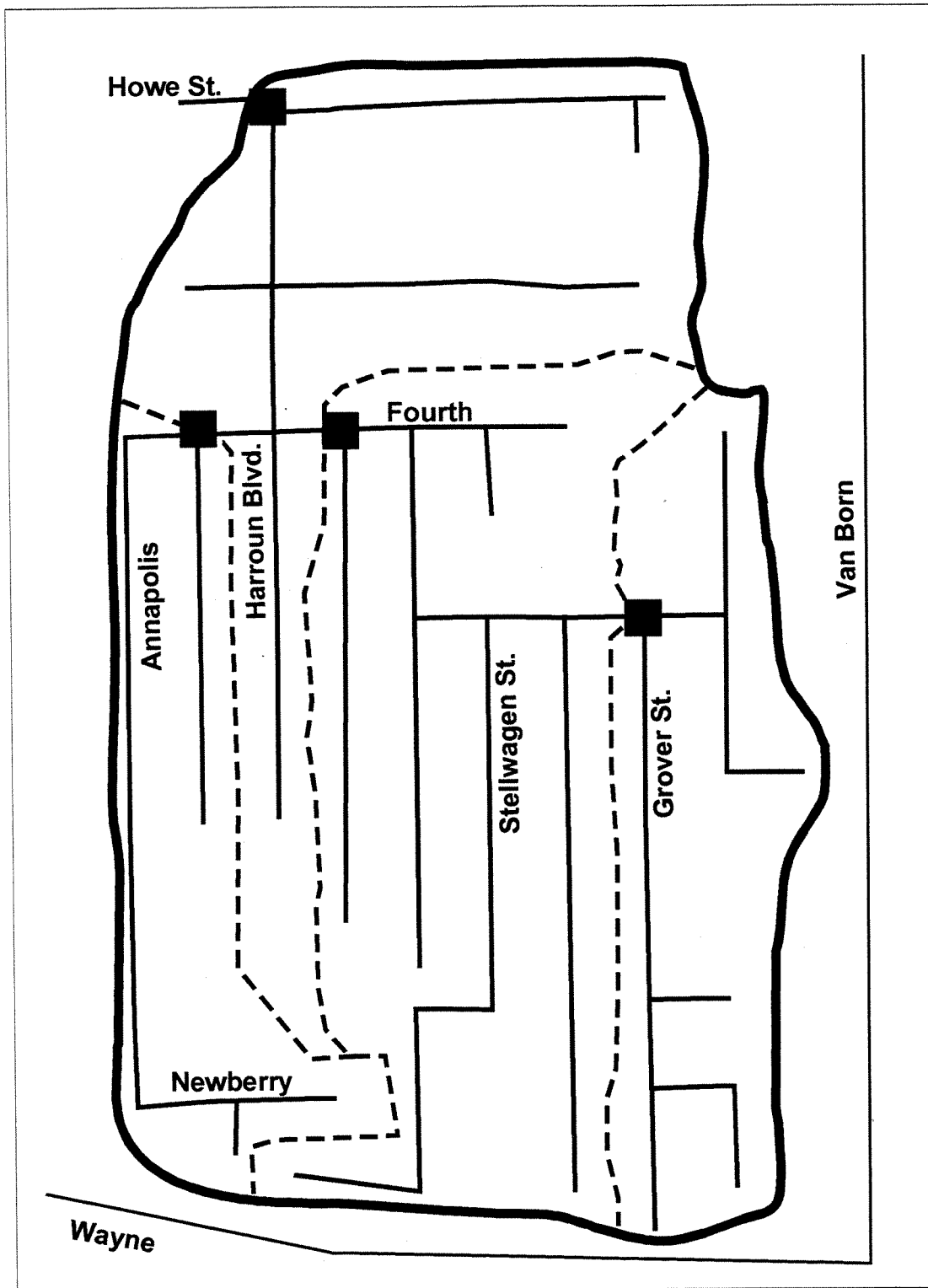
SAMPLING AND ANALYSIS

Sampling Locations

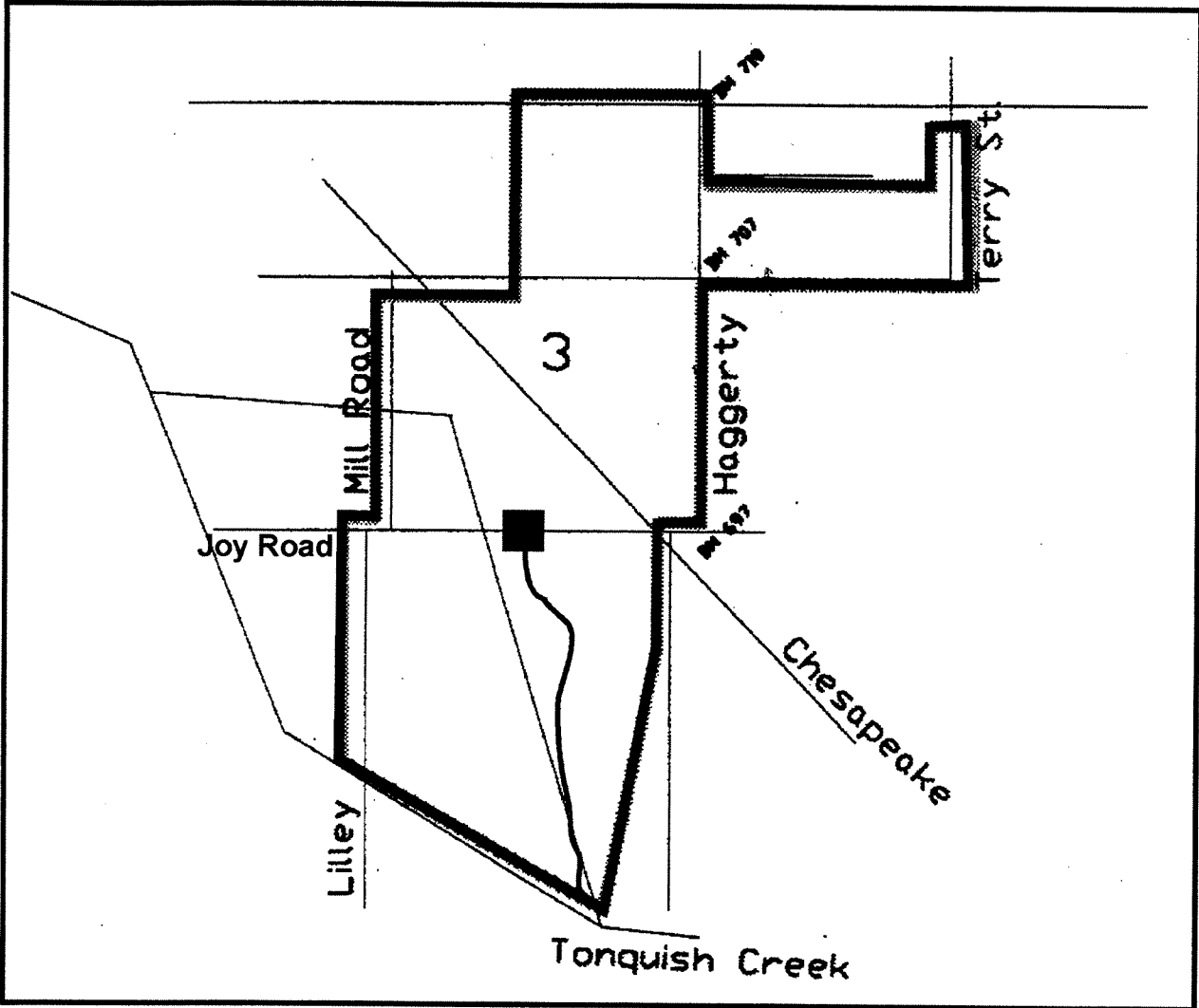
Samples of sanitary and storm sewer water, groundwater, and domestic (tap) water from four mini watersheds were analyzed for their oxygen and hydrogen isotopic compositions. Two of the watersheds discharging at outfalls WA36 and WA65 were located in Wayne, Michigan, (Figures 3 and 4). Discharge into WA36 is carried through two subsets of sewers, WA36-East and WA36-West, which join at the outfall (Figure 3). In the second watershed, storm sewers from a residential area discharge at outfall WA65 (Figure 4). Wayne County has previously investigated the industrial sources of discharge using smoke and dye testing, and all industrial connections to WA36 are believed to have been removed. No testing has been performed in the residential area sewers discharging at WA65, and the sources of dry weather flow are not known. A third mini watershed selected for this study was the outfall of the Koss Drain at Joy Road (Figure 5). The sources of flow in this sewer also are not known, but illicit connections are suspected. Limited samples were obtained from a fourth area at Gregory Street near Dearborn, Michigan, to test the validity of the isotopic technique in an area where sanitary connections in the storm sewer are known to be present. In addition, a groundwater sample was obtained from a monitoring well located within about 4 km of outfall WA36. The sampling of this well was permitted on the condition that we do not reveal the precise location of the well.



**Figure 3. Previously Investigated Sample Area
Wayne, Michigan
Drain WA-36**



**Figure 4. Residential Sample Area
Wayne, Michigan
Drain WA-65**



**Figure 5. Suspected Problem Area
Plymouth Township
Koss Drain**

The storm sewer samples were collected at least 72 hours after a precipitation event. In addition, samples of nearby sanitary sewers and of tap water were collected. Samples of dry weather flow were taken with a device developed by McNamee, Porter and Seeley, Inc. This device allows sampling from the ground in a manhole with very small flow. Sampling was conducted in two rounds. The first round was conducted during September 1995, and samples were collected from: (a) storm sewers feeding outfalls WA36 and WA65; (b) the Koss Drain; (c) sanitary sewers in the vicinity of WA36, WA65 and Koss Drain; and (d) tap water from buildings in the area of WA36 and WA65. In the second sampling round, conducted during November 1995, additional samples were collected in the west sewer system feeding outfall WA36, Gregory Street sewers, as well as groundwater in the vicinity of WA36.

Isotopic Analysis

Isotopic analyses were performed at the Geochron Laboratories, Cambridge, Massachusetts. For oxygen isotope analyses, an aliquot of the water was equilibrated with carbon dioxide for 24 hours in a water bath. The CO₂ was then used to measure isotopic ratios on a stable isotope ratio mass spectrometer. For hydrogen isotopes, the water sample was reduced by heating with uranium to produce hydrogen gas. Hydrogen was separated from other gases by freezing over a charcoal trap and used for mass spectrometric measurements. The errors of measurement are +/-0.1 per mil for oxygen and +/-2 per mil for hydrogen isotopes. Results of the analyses are listed in Table 1.

Table 1. Stable oxygen and hydrogen isotope compositions of storm and sanitary sewer, tap water and groundwater samples collected during September and November 1995.

Sample Location*	Month	$\delta^{18}\text{O}^{**}$	δD^{**}
Storm Sewers			
<i>Outfall WA65</i>			
Winslow/4th	September	-8.9	-63
Richard/4th	September	-9.2	-66
Howe St-48"	September	-9.1	-65
Glover/2nd	September	-9.2	-66
<i>Outfall WA36</i>			
East MI Av-96" (WA36-East)	September	-9.1	-63
West MI Av-96" (WA36-West)	September	-7.8	-57
Main + Newberry South	November	-11.2	-84
Park + Newberry West	November	-13.6	-101
Newberry s. ROW MiAv	November	-12.1	-89
Elizabeth S. RR	November	-15.8	-115
Elizabeth S. + Mi Av	November	-15.7	-113
<i>Koss Drain/Gregory St.</i>			
Koss Drain	September	-8.6	-64
Gregory St	November	-7.8	-65
Sanitary Sewers			
MI Av-96" (WA36)	September	-7.2	-54
Howe St-48" (WA65)	September	-7.1	-56
Park+Newberry (WA36)	November	-7.4	-62
Koss Drain	September	-7.1	-56
Gregory St	November	-6.9	-58
Tap Water (near WA36/WA65)			
Howe St	September	-6.9	-54

Sample Location*	Month	$\delta^{18}\text{O}^{**}$	δD^{**}
Main St. post office	November	-7.0	-59
Elizabeth Rd 35660	November	-6.8	-58
Groundwater near WA36***			
T2R9	November	-8.3	-58

- * refer to Figures 3-5 for locations for all areas except the Gregory St. area
- ** in per mil, SMOW; the errors of measurement are: ± 0.1 for $\delta^{18}\text{O}$ and ± 2 for δD
- *** within about 4 km of outfall WA36

RESULTS AND DISCUSSION

Sources of Water

The stable oxygen and hydrogen isotope compositions of tap water and a groundwater sample from the Wayne, Michigan, area are shown in Figure 6. Tap water samples have a narrow range of isotopic compositions ($\delta^{18}\text{O} = -6.8$ to -7.0 and $\delta\text{D} = -54$ to -59 per mil) and plot to the right of the MWL. This is because domestic water in the area is obtained primarily from nearby lakes and, therefore, will be expected to show isotopic enrichment due to surface evaporation.

The isotopic composition of the shallow groundwater sample lies along the MWL, indicating an origin from local precipitation. The groundwater composition is much different than that of tap water. This groundwater sample was collected within about 2 miles of the Outfall WA36 sampling locations. The isotopic composition of the groundwater sample may not be precisely the same as that in the sampled area, but the general relationship between groundwater and tap water samples is likely to be the same.

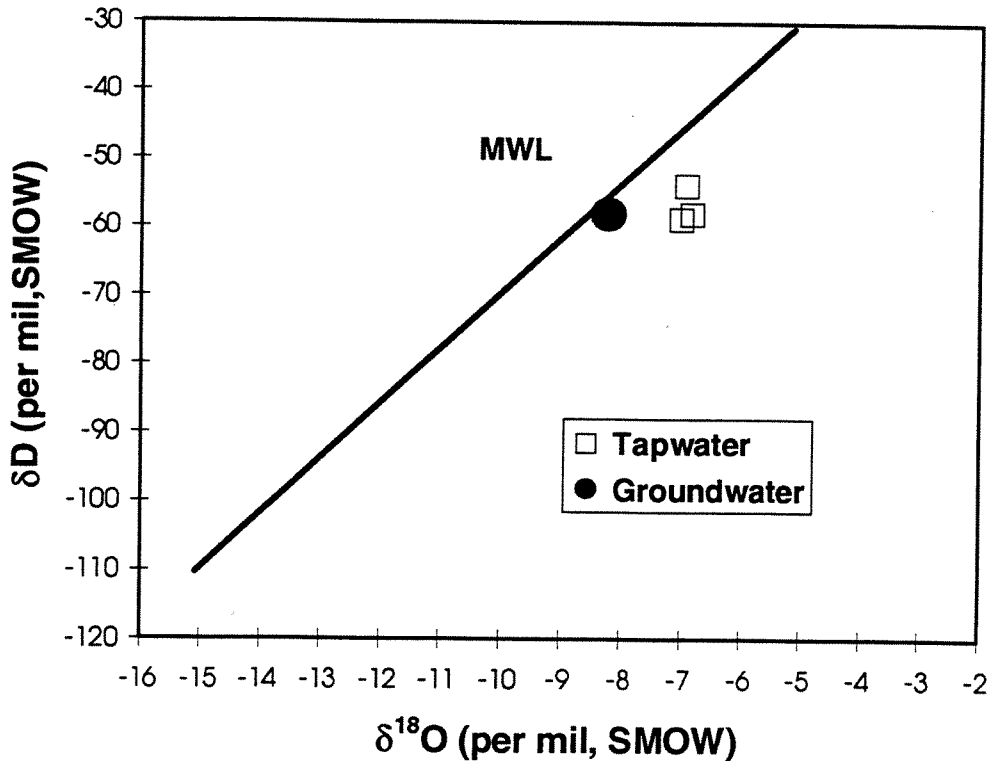


Figure 6. Isotopic Composition of Tap Water and Groundwater from WA36 and WA65 Areas.

Outfalls WA36 and WA65

Isotopic compositions of storm and sanitary sewers in the areas of outfalls WA36 (East and West) and WA65 are shown in Figure 7. The sanitary sewer samples have isotopic compositions similar to those of the tap water samples. Sanitary flow originates from domestic and industrial use of local water supply and, therefore, it is isotopically the same as the tap water. Isotopic compositions of the storm sewer samples collected in September 1995 fall into two groups. Samples from WA65 and WA36-East have a very narrow range of isotopic values ($\delta^{18}\text{O} = -8.9$ to -9.2 and $\delta\text{D} = -63$ to -66 per mil) and plot along the MWL. The isotopic composition of storm sewer samples are much different than those of the sanitary sewer and tap water samples but are similar to that of the local groundwater. The very tight range of values for the storm sewer samples indicates the influx of shallow groundwater, rather than surface runoff, in the storm sewer.

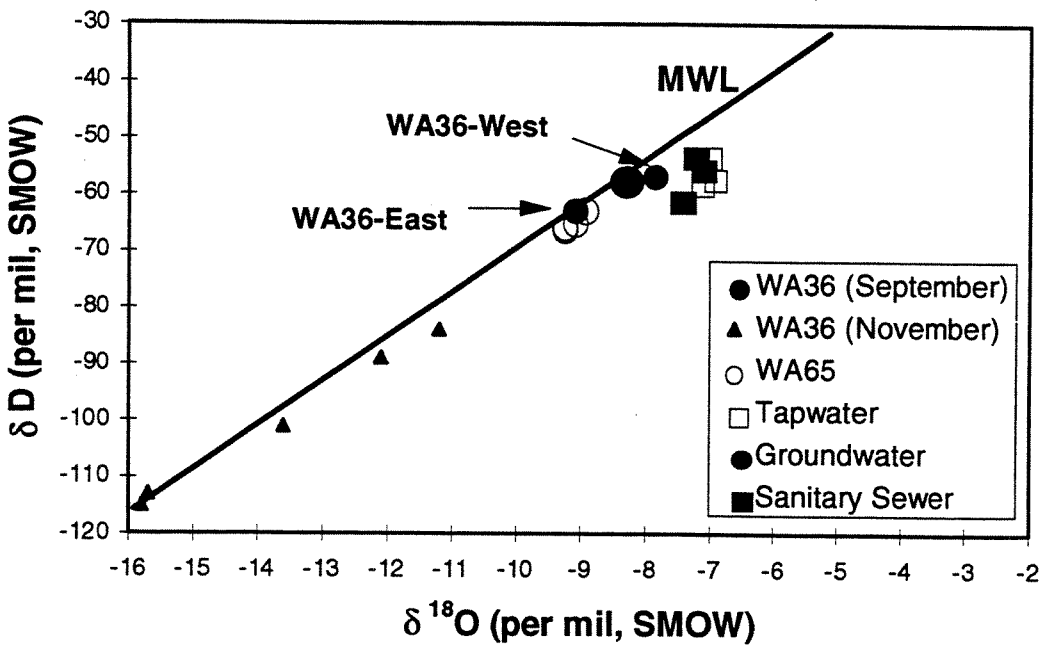


Figure 7. Isotopic Composition of Storm and Sanitary Sewer Samples from WA36 and WA65 Areas. Compositions of Tap Water and Groundwater are Shown for Comparison.

In the WA36-West sewer system, oxygen and hydrogen isotopic values of the storm sewer sample ($\delta^{18}\text{O} = -7.8$ per mil and $\delta\text{D} = -57$ per mil) are shifted towards those of the tap water/sanitary sewers. This indicates that a substantial portion of the flow in WA36-West sewer originates from industrial or domestic sources using city water supply. This result was unexpected because all known illicit connections to this sewer system had been previously eliminated. A second round of sampling was conducted upstream of the WA36-West sampling location to isolate the area of the suspected illicit discharge. This sampling was conducted in November 1995. The isotopic compositions of all of the samples were much lower (more negative) than those found in the first round of sampling (Figure 7). These lower values indicate the presence of snowmelt in the storm sewer during the sampling event. This shows that snowmelt may produce runoff for a longer period of time than that in the summer

seasons, and sampling for isotopic studies should carefully account for this source of flow in storm sewers.

Koss Drain and Gregory Street Sewer

The isotopic compositions of storm and sanitary sewer samples from these two areas are shown in Figure 8. Isotopic composition of storm sewer sample from the Koss Drain ($\delta^{18}\text{O} = -8.6$ per mil and $\delta\text{D} = -64$ per mil) plots below the MWL and is shifted towards the sanitary sewer composition. Assuming that isotopic composition of groundwater in the Koss Drain area is similar to that observed in the WA36 and WA65 areas, the slight shift in the Koss Drain oxygen isotope values may indicate the presence of industrial/domestic discharge, but only as a small proportion of the total dry weather flow. Note that many illicit connections are suspected in this sewer.

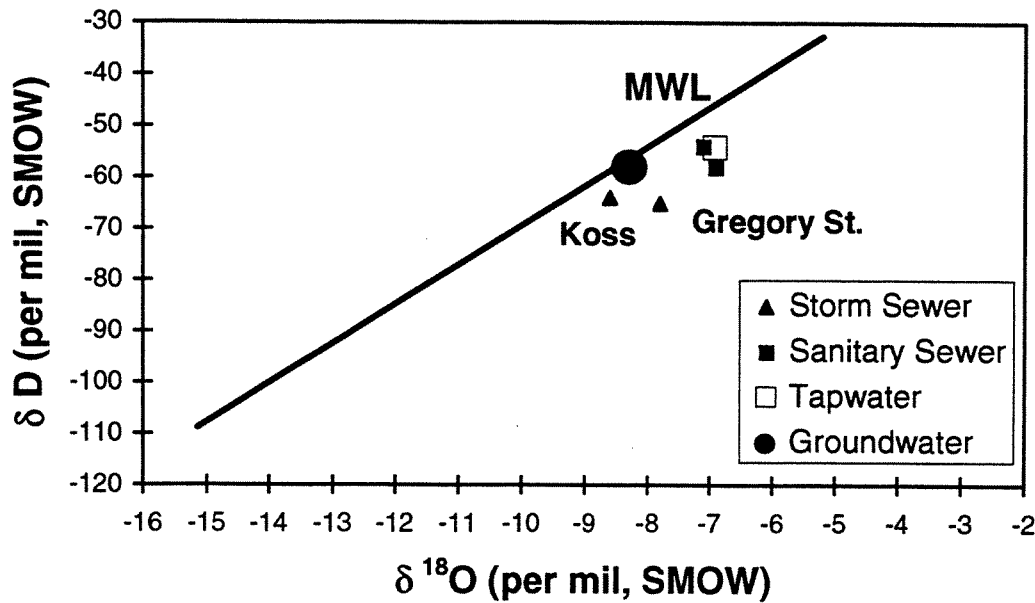


Figure 8. Isotopic Composition of Storm and Sanitary Sewer Samples from Koss Drain and Gregory St. Compositions of Tap Water and Groundwater from WA36 area are Shown for Comparison.

Isotopic composition of the Gregory Street storm sewer sample ($\delta^{18}\text{O} = -7.8$ per mil and $\delta\text{D} = -65$ per mil) plots significantly below the MWL and is shifted towards the sanitary sewer sample (Figure 8). This indicates the presence of tap water from domestic or industrial sources in the storm sewer. The Gregory Street storm sewer is known to have many sanitary connections (not illicit). Results of the isotopic analyses from the Gregory Street sewer, therefore, demonstrate the validity of the isotopic technique in identifying sanitary connections.

CONCLUSIONS

Stable isotope analyses of storm and sanitary sewer samples from the Rouge River Watershed near Wayne, Michigan, indicate that the stable oxygen and hydrogen isotopic compositions provide a means for rapid determination of the presence or absence of domestic or industrial discharge in storm sewers.

Results of the feasibility study indicate that the use of stable oxygen and hydrogen isotope compositions allows rapid determination of the presence or absence of domestic or industrial waste in storm sewers. This conclusion has important implications for illicit connection elimination efforts, particularly in residential areas, where use of traditional methods (smoke and dye testing) is cost-prohibitive; relatively large residential areas may be precluded from detailed investigations of illicit connection identification at significant cost savings, using the isotopic approach. In areas where the presence of domestic flow is indicated, a limited area may be isolated for detailed investigations. We are presently conducting a pilot study to apply the methodology to several small sub-watersheds in the Rouge River Watershed. We are developing sampling and other protocols for using the isotope analyses to identify illicit connections on a large watershed scale. Another goal of this pilot study is to evaluate the combined use of stable oxygen, hydrogen, carbon, and nitrogen isotopes to distinguish between domestic and industrial sources of illicit discharge.

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