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Hand Delivered December 21, 2018

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DEC 21 2018
Regional Forester's Office

re: Prince of Wales Landscape Level Analysis Objections

Regional Forester Schmid:

The Southeast Alaska Conservation Council (SEACC and the Alaska Community Action on Toxics (ACAT) object to the October 2018 Final Environmental Impact Statement (FEIS) and the draft Record of Decision (Draft ROD) for the Prince of Wales Landscape Level Analysis (POW LLA). Earl Stewart, the Tongass Forest Supervisor is the responsible official for the Draft ROD and FEIS for the POW LLA Project. These objections supplement the more extensive objections submitted by Earthjustice on behalf of SEACC and others on December 21, 2018. Based on the corrected legal notice published in the Ketchikan Daily News on November 16, 2018, these objections are timely.

SEACC and ACAT submitted timely, specific, and substantive comments regarding the proposed project on the draft EIS for this project on June 18, 2018. We submitted those comments via both email and direct mail. For purposes of 36 C.F.R. § 218.8(d)(l), the objecting parties may be reached via the SEACC contact information indicated in the signature block. For purposes of 36 C.F.R. § 218.8(d)(3), SEACC is the lead objector.

I. POW LLA PROJECT'S CONDITION-BASED PLANNING APPROACH VIOLATES NEPA.

The Draft ROD proposes to authorize a wide array of site-specific activities over the next 15 years under the umbrella of this FEIS, including old-growth logging, new road construction, and management of invasive plants with herbicides.[1] It tries to do so, however, without providing agency decision-makers and the public with the detailed, site-specific analysis

[1] *See* POW LLA FEIS, Summary, at S-1 and S-2.

necessary to make reasoned choices among proposed action alternatives. Instead of deferring final decisions regarding specific activities until after the agency discloses and evaluates the precise timing, size, and location of the proposed activity, including the selection of appropriate design components or mitigation measures, the Forest Supervisor prematurely selected Alternative 2 in full. Although the agency has provided the public with an opportunity to object to the Draft ROD, it fails to provide the public with the opportunity to object after the Line Officer's response to public comment at the completion of Stage 4, following the agency initial disclosure to the public of precise activity-specific details.

While the Selected Alternative remains subject to requirements within the Activity Cards (Appendix 1 to the Draft ROD) and processes described in the Implementation Plan (Appendix 2 to the Draft ROD), these subsequent actions and processes occur <u>after</u> the agency has made a go-no-go decision.[2] This is precisely the type of environmentally blind decision-making Congress intended NEPA to avoid.[3]

For purposes of this objection, SEACC and ACAT focus on the problems presented by using this "large landscape-scale analysis" approach to address the environmental consequences from carrying out approved invasive plant management treatments. The Forest Supervisor explains in the Draft ROD that he modified Alternative 2 "to incorporate the use of herbicide treatments on invasive plant populations (as described in Alternative 3 of the FEIS to keep the infestation of noxious and invasive weeds on NFS lands to a minimum in accordance with Executive Order (EO) 13112 (1999)."[4] Such "[h]erbicide use will be planned by prioritizing infestations based on species and size, following project design feature implementation, adhering to herbicide label requirements, the Pesticide Use Proposal process, and permitting and/or regulatory processes (all built into a site-specific Weed Management Plan)."[5] "A comprehensive planning process prior to

[2] *See* Draft ROD at 1, 2.
[3] *See Conner v. Burford*, 848 F.2d 1441, 1451 (9th Cir. 1988); *see also Robertson v. Methow Valley Citizens Council*, 490 U.S. 332,349 (1989)(NEPA's action-forcing procedures "ensure[] that important effects will not be overlooked or underestimated only to be discovered <u>after resources have been committed</u> or the die otherwise cast.")(emphasis added, citations omitted).
[4] Draft ROD at 5.
[5] *Id.at* 1.

treatment, which includes site-specific design features for each resource, will further mitigate risks. [6]

These conclusions are arbitrary because the Forest Supervisor offers an explanation that runs counter to the evidence presented in the FEIS." [7] As noted there,"[u]ndeveloped lands in the project area have relatively few Invasive plant infestations."[8] "Roads are conduits for the spread of weeds, facilitating their rapid transport and dispersal."[9] "[I]nvasive species generally do not occur within old growth forest but rather on the edges of this habitat. Disturbance of the old-growth and young-growth forest habitats can introduce invasive plants into the bare mineral soil exposed during logging operations." [10] "Timber harvest, road building, and other ground-disturbing activities contribute to the spread of weeds." Consequently, the more acres disturbed by proposed activities, "the greater risk ofto thespread or introduction of invasive plants."[11]

II. FOREST SERVICE VIOLATED NEPA BY FAILING TO DISCLOSE AND EVALUATE RESPONSIBLE OPPOSING VIEWPOINTS.

In response to the Draft Statement of Issues and Alternatives released for this project, Earthjustice submitted comments on behalf of SEACC and others that specifically noted "[t]he scope of potential impacts from the use of herbicides is particularly significant on Prince of Wales and surrounding islands due to the high solubility ofkarst landscapes." *See* PR# 833-0175 at 4. Given the paucity of site-specific information and analysis in the DEIS regarding this significant issue, SEACC and ACAT raised concerns about the evaluation's adequacy as to the full scope of potential impacts from the use of herbicides for invasive plant management.[12] We

[6] Draft ROD at 7.
[7] *Id.* at 43.
[8] FEIS at 3-248.
[9] *Id.* at 3-249.
[10] *Id.* at 3-251.
[11] *Id.* at 3-352.
[12] *See* PR# 833_1634 at 7.

also submitted responsible opposing viewpoints on this significant issue from Thomas J. Aley, President of the Ozark Underground Laboratory in Missouri.[13]

The Forest Service violated NEPA by failing to disclose and analyze these responsible opposing scientific viewpoints in the FEIS as required by regulations issued by the Council of Environmental Quality (CEQ).[14] Federal courts give substantial deference to and strictly interpret CEQ regulations "to the fullest extent possible."[15] NEPA's '"action-forcing' procedures ... require the Forest Service to take a 'hard look' at environmental consequences,"[16] *before* the agency approves an action. "By so focusing agency attention, NEPA ensures that the agency will not act on incomplete information, only to regret its decision after it is too late to correct."[17] CEQ regulations also obligate the Forest Service to respond to arguments presented to the agency in response to public comment on the DEIS. *See* 40 C.F.R. § 1503.4(a).

The objectors found no clear evidence in the agency's response to our comments, the FEIS, or supporting resource reports, that the agency took a hard look at the synergies between the effects of spraying pesticides on highly soluble karst topography and potential contamination of groundwater and aquatic resources. None of the resource reports for aquatics, hydrology, or

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[13] Mr. Aley's work includes a number of groundwater tracing investigations on Prince of Wales, Tuxekan, Heceta, Kosciusko, and Chichagof Islands in Southeast Alaska. In 1993, Mr. Aley prepared the *Karst and Cave Resource Significance Assessment,* for the Ketchikan Area, Tongass National Forest, Alaska. *See* POW LLA Planning Record (PR# 833-0610). Mr. Aley also participated in the initial development ofkarst vulnerability standards for the Tongass National Forest, as well as a 2002 review of the standards and their implementation. *See* PR,# 833-0611 *(Final Report of the Karst Review Panel* (Dec. 2002)). Mr. Aley was one of the authors of the Water Tracer's Handbook (1976). These dye tracing methods were adopted for *Delineation of a Karst Watershed on Prince of Wales Island, Southeast Alaska* (2007) (PR# 833_0612).
[14] *See* 40 C.F.R. § 1502.9(b).
[15] *Marsh v. Or. Natural Res. Council,* 490 U.S. 360, 372 (1989)(intemal citations omitted); *Cal. v. Block*, 690 F.2d 753, 770-71 (1982)("NEPA's public comment procedures are at the heart of the NEPA review process [and] reflects the paramount Congressional desire to internalize opposing viewpoints into the decisonmaking process to ensure that an agency is cognizant of all the environmental trade-offs that are implicit in a decision.'")(supporting citations omitted).
[16] Metcalf v. Daley, 214 F.3d 1135, 1141 (9th Cir. 2000) *(quoting* Robertson v. Methow Valley Citizens Council, 490 U.S. 332, 348 (1989)).
[17] *Id.* (citation omitted).

soils and wetlands cite any of the materials submitted by SEACC and ACAT on the DEIS.[18] Without providing evidence of its reasoning in the FEIS or supporting resource reports, the agency's conclusion of negligible effects is arbitrary and it cannot demonstrate it took a hard look at the responsible opposing scientific viewpoints submitted for the record.

III. FAILURE TO REQUIRE KARST VULNERABILITY ANALYSIS BEFORE TREATING KARST VIOLATES THE NATIONAL FOREST MANAGEMENT ACT AND THE 2016 TONGASS LAND MANAGEMENT PLAN.

The Forest Service violates NFMA when it acts contrary to a governing forest plan.[19] Standards established in forest plans "are binding limitations typically designed to prevent degradation of current resource conditions." [20] Thus, "[a] site-specific project must comply with the standards set forth in the governing forest plan, and a project's deviation from a standard requires amendment to the forest plan."[21]

The 2016 Tongass Land Management Plan (TLMP) requires the Forest Service to inventory and classify karst and cave resources based on resource values and sensitivity to change. To meet the direction provided by the Federal Cave Resources Protection Act (FCRPA), regulations, and agency policy, the TLMP establishes forest-wide standard and guidelines for managing karst and cave resources to comply with the requirements of the FCRPA Act and applicable regulations and policy.[22] As pointed out in the POW LLA FEIS, to comply with TLMP "[a] karst resource vulnerability assessment is conducted for each project regardless of its scale." [23]

TLMP directs the agency to:

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[18] Only two resource reports, Schneider (2018)(PR # 833-1063) and Whitacre (2018)(PR # 833_1069), reference any of the documents submitted by SEACC and ACAT for the record. Bibliographies for both resource reports cite Norris, et al. (1991)(PR# 833-1109).
[19] *See* 16 U.S.C. § 1604(i)("Resource plans and permits, contracts, and other instruments for the use and occupancy of National Forest System lands shall be consistent with the land management plans.").
[20] All. for the Wild Rockies v. United States Forest Serv., 907 F.3d 1105, 1113 (9th Cir. 2018)
[21] *Id*
[22] *See* TLMP, KCI.II.A at 4-23; *see also* TLMP, Appendix H.
[23] POW LLA FEIS at 3-253.

> Evaluate karst resources as to their vulnerability to land uses affecting karst systems, as described in the Karst and Cave Resource Significance Assessment, Ketchikan Area, Tongass National Forest, Alaska (Aley et al. 1993), Karst Landscapes and Associated Resources: A Resource Assessment (USDA Forest Service Gen. Tech. Rep. PNW-383) (Baichtal and Swanston 1996), Karst Management Standards and Implementation Review, Final Report of the Karst Review Panel (Griffiths et al. 2002), and the information provided herein.

> Karst resources must be evaluated according to their vulnerability to land uses affecting karst systems.[24]

Activity Card # 35 is the only activity card applicable to activities involving herbicidal treatment of invasive plants. Resource-specific guidelines on Activity Card #35 for Geology/ Karst provide:

> Review treatment plans with the District/SO Geologist or Karst Specialist.
> All hydrology and fisheries project design features will be applied to high and moderate vulnerability karst systems for both surface and subsurface aquatic systems.[25]

Importantly, this language does not require the Forest Service to conduct a karst vulnerability analysis before applying herbicides on karst terrain. Therefore, this outcome is inconsistent with TLMP provisions, a violation ofNFMA.

A review of applicable Project Design Feature (PDF) contained in Krosse (2018) include one that relates directly to both high and moderate vulnerability karst. This PDF, however, does not require a karst vulnerability assessment <u>before</u> implementation of herbicidal treatment of invasive plants on karst. PDF # 49 states:

> Stream and other aquatic PDFs will be applied to high vulnerably karst sites (see Hydrology and Aquatic Organism Resource Reports). Moderate vulnerability karst should be assessed for openness by a karst management specialist prior to treatment and will follow all PDFs as applicable. Herbicides are suitable on low vulnerability karst (See Aquatic/Hydro PDFs).[26]

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[24] 2016 TLMP, App. H-Karst and Cave Resources, Karst II.A. and Karst III.A, at H-1.
[25] POW LLA FEIS., App. A-Activity Cards, Card# 35 at A-161; Draft ROD, App. 1 at 1-158.
[26] *Id.*, Appendix B at 109.

Notably, neither the Hydrology nor Aquatic Organism Resource Reports, require performance ofkarst vulnerability assessments before conducting herbicidal treatment on karst terrain as required by the 2016 TLMP.[27]

In response to comments submitted on the DEIS, the FEIS states:

> As outlined in the Implementation Plan (Appendix B, page 13), each site where any treatment is proposed will undergo a comprehensive process that includes development of a weed management plan that then is reviewed by IDT resource specialists. Where karst is concerned, the plan would need approval from a certified Geologist that may include specific recommendations for mitigation measures. Any sites where herbicide use is proposed will additionally require a Pesticide Use
>
> Proposal (PUP) that is then further reviewed by the Regional Pesticide Use Coordinator and approved by the Regional Forester or other delegated official before implementation.[28]

This response does not cure the inconsistencies noted above. Contrary to the agency's response, nothing in the comprehensive invasive plant treatment strategy requires "approval from a certified Geologist." Although Activity Card #35 calls for review of treatment plans by "the District/SO Geologist or Karst Specialist," it does not require preparation of a karst vulnerability assessment or allow the Geologist to delay implementation until completion of the assessment. Likewise, nothing in the PUP requires completion of a karst vulnerability assessment or approval by a certified Geologist before implementation.[29]

In contrast to the equivocal nature of the above PDFs, Aley asserts that "[t]he karst vulnerability classes are critical to the evaluation of land management activities on karst resources and the karst groundwater system." [30] The Forest Service's failure to examine the Aley

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[27] *See* PR# 833_1069 at 27-29 (PDFs for Hydrology) PR# 833_1063 at 19-21 (PDFs for Aquatic Resources)
[28] FEIS, App. D
[29] *See* FEIS, App. B - Implementation Plan at B-17 (requiring completion and approval of PUP by "the Regional Pesticide Use Coordinator, and approved by the Regional Forester or other delegated official before implementation (footnote omitted)." *See also* Krosse (2018e) at 99-104 (PR# 833_1056).
[30] *See* Aley's Report (June 28, 2005)(PR # 1919 Lit_1919). This document is referenced in PR# 833_1972 ("Index displaying documents cited as exhibits or attachments by ... SEACC in Letter #833_1634, ... Most of these documents were not cited in the POW LLA analysis. If

Report and articulate a satisfactory explanation for not requiring a karst vulnerability analysis before spraying any herbicides on karst terrain is arbitrary and violates NFMA.

IV. FINDING OF"NO EFFECT" FROM APPLYING HERBICIDES ON HIGH VULNERABILITY KARST IS ARBITRARY.

According to the FEIS, there will be "[n]o effect [from applying herbicides on high vulnerability (open) karst systems] due to implementation of hydrology and aquatic PDFs." [31] Krosse (2018) asserts that:

> The impact from herbicide treatment on waters within high vulnerability karst ecosystems and their dependent aquatic organisms, water quality (both surface and subsurface) and soil productivity is negligible because project design features developed for Hydrology and Aquatic Organisms are used to provide additional precautions."[32]

The FEIS explains that it based its conclusions on full analyses contained in the applicable resource reports and by use of available scientific risk assessments "synthesized in Krosse (2018d)."[33] This conclusion is reasonable, however, only if the agency can demonstrate that it examined the relevant data, articulated a satisfactory explanation for its action, and provided a "rational connection between the facts found and the choice made."[34] A decision is arbitrary if the agency "entirely failed to consider an important aspect of the problem" or

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they were cited, they are included in the POW LLA Project Record and POW LLA Project Record Index. The remainder of the documents are filed at the Thome Bay Ranger District Forest Service Office on jump drivels, CD, and a hard drive."). In preparing these objections, SEACC realized that we had submitted miss-scanned copy of Aley's Report. Consequently, we submit a corrected scan of the Aley Report (with attachments) with this objection.

[31] *Id.* at Table 6, at 3-74.

[32] PR# 833_1056 at 36-37; *id.* at 22 ("no impact due to implementation of hydrology and aquatic PDF's."); *see also* Foss (2018)(PR # 833_1072 at 15).

[33] FEIS at 3-72.

[34] Motor Vehicle Mfrs. Ass'n of the U.S. v. State Farm Mut. Auto. Ins. Co., 463 U.S. 29, 43 (1983) (quoting Burlington Truck Lines v. United States, 371 U.S. 156, 168 (1962)).

"offered an explanation for its decision that runs counter to the evidence before the agency."[35] Similarly, an action may be arbitrary if the record does not support the agency's reasoning.[36]

The agency's conclusion is arbitrary for several reasons. First, use of the cited SERA risk assessments (SERA, 2007, 2011a, 2011b) did not follow agency direction because none evaluated literature published or unpublished after 2011.[37] Consequently none of "[t]he SERA risk assessment synthesize all known studies" because objectors provided multiple studies with our comments on the DEIS that were published after the date of the latest SERA risk assessment used for this project but never looked at.[38] The assessment for Aminopyralid [39] is dated June 28, 2007, and the latest assessment for Glyphosate[40] is dated March 25, 2011. The final SERA risk assessment for Imazapyr is dated December 16, 2011.[41] The most recent report on adjuvants is from January 1, 2007.[42]

For purposes of evaluating effects in karst landscapes, Foss (2018) uses the potential for herbicides to enter subsurface waters systems. [43] For example, Foss (2018) concludes that "Imazapyr degrades quickly in water by sunlight so water contamination is minimized" and concludes that microbial degradation [and] microbial degradation . . . are complex biochemical reactions that ultimately tum the herbicides into inert salts and carbon dioxide."[44]

As emphasized by Aley:

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[35] Id. at 43.
[36] See, e.g., Ctr. for Biological Diversity v. NHTSA, 538 F.3d 1172, 1201-03 (9th Cir. 2008); Pac. Coast Fed'n of Fishermen's Ass'ns v. NMFS, 265 F.3d 1028, 1037-38 (9th Cir. 2001).
[37] *See* Kresse (2018e)(PR # 833_1056) at 31; PR# 833_1005, § 1.3 at 12-15 (Preparation of Environmental Documentation and Risk Assessments for the USDA/Forest Service).
[38] Compare Foss 2018 (PR# 833_1072 at 6)(cited in K.rosse 2018e, Table 3 at 22 for measuring effects to soil productivity, wetlands, and high vulnerability karst) *with* Van Bruggen et al. (2018)(PR # 1922 Lit_1922) at 257 (citing multiple post 2012 studies on transport of glyphosate due to rain and erosion); Mesnage, R. et al. (2015) at 8 (residues in drinking water)(PR # 1914 Lit 1914).
[39] PR # 833_0448 (June 28, 2007).
[40] PR# 833_0449 (Mar. 25, 2011).
[41] PR# 833 0447.
[42] PR# 833 1075.
[43] PR# 833 1072 at 9.
[44] *Id.* at 8, 14.

> There is no sunlight present in groundwater systems, including karst groundwater systems. Photodegradation is also appreciably reduced in the shade beneath the tree canopy..... In a karst aquifer (sic) any degradation oflmazapyr will be primarily or perhaps exclusively due to microbial metabolism, and such herbicide metabolism rates will be orders of magnitude slower than in soils where there are larger microbial populations. The fact that there are orders of magnitude larger microbial populations in the soil than in the karst groundwater system is well known to biologists who routinely work with caves.[45]

Similarly, Krosse (2018e) downplays current infestations of invasive plants on high vulnerability karst "[because] the issues related to karst ecosystems are the same as the issues related to herbicide effects to water quality and aquatic organism."[46] Further, Krosse (2018e) concludes "although some adverse effects from these actions are unavoidable," overall effects of herbicides "are not expected to be measurable" to high vulnerability karst, because project design features will minimize adverse effects to high vulnerability karst.[47]

However, Aley cautions that "herbicide degradation to harmless compounds is much slower in groundwater systems than in soils [because] of magnitude lower levels of microbial activity in groundwater" and "the [rapid] rates of water movement through the karst groundwater systems of southeast (sic) Alaska."[48] Aley faults the assumption that "most of the herbicides reaching the forest floor would be retained or destroyed in the soil prior to entry into the karst groundwater system" because "water and contaminant migration from the forest floor into the underlying karst conduits during precipitation events is extremely rapid, and as a result the soils will not provide effective adsorption and degradation of the herbicides."[49]

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[45] Aley's Report at 8 (PR# 1919 Lit_1919).
[46] Krosse (2018e)(PR # 833_1056) at 31
[47] *See id.*, at 34; *see also id.105* - 109 (Appendix B, Project Design Features).
[48] Aley's Report at 10; *see also*
[49] Aley's Report at 10 (referencing USGS (2002) to demonstrate "that herbicides are not effectively detained and degraded in the soil overlying karst units, but instead move through these soils and into karst aquifers and their receiving springs.").

A review of the Project Design Features in Krosse (2018e) offers additional examples of how the Forest Service failed to carefully consider issues raised in the Aley Report. First, PDF #16 requires "[m]arker dye to be used to mark where herbicides have been applied to avoid over spraying." However, Aley plainly indicates that how important dye tracing is before application of herbicides to determine whether pesticides would enter underground streams.[50]

Next, PDF #19 provides that "[h]erbicides will not be applied immediately prior to, during, or immediately after a rain event at the treatment site." However, as Aley notes, "[i]t rains frequently, in appreciable quantities, and in all seasons in Southeast Alaska; that is why the area is classified as a temperate rainforest."[51] He also notes "a well-developed (sic) and hydrologically integrated karst groundwater system [is] capable ofrapidly draining overlying and adjacent tributary lands and conveying the water rapidly through caves and karst groundwater conduits to springs which will be both inside and outside of the planned spray area." [52] These facts are important because:

> The chance that one or more precipitation events capable of washing more than half of this water soluble and highly mobile herbicide off plants and onto ·the forest floor is very high. Based upon the precipitation patterns [on Long Island, adjacent to Hydaburg on Prince of Wales Island] DEC should assume that more than half of the Imazapyr applied under the permit will reach the forest floor.[53]

The above discussion demonstrates how little attention the Forest Service gave to the effects of herbicide contamination of groundwater in karst systems and the Aley Report. The failure to consider important aspects of the problem makes the "no effect" findings in the resource reports' arbitrary with regard to karst groundwater.

Finally, we point out the significance of these errors given the existence of rare amphipods associated with karst. According to the FEIS:

> Two cave obligate amphipod species are being specifically considered in this project: one is *Stygobromus quatsinensis*, described in 1987 (Holsinger and Shaw 1987), and the other is an undescribed species of the same genus (Holsinger *et al.* 1997). These amphipods are being specifically considered in this project because

[50] *Id.* at 4.
[51] Aley Report at 6
[52] *Id.* at 5.
[53] *Id.* at 7.

> they are thought to be rare and a majority of their documented occurrences are within the project area. *Stygobromus quatsinensis* was initially discovered in caves on Vancouver Island, British Columbia, and a majority of its documented occurrences have been in the project area in springs and caves on Heceta, Dall, Baker, Suemez, and Coronation islands. *Stygobromus* n sp. is only known to occur in El Capitan, Lower El Capitan, and Starlight cave systems on Prince of Wales Island. These cave dwelling species have specific karst habitat requirements and are sensitive to changes in water quality, especially temperature and pH (Holsinger *et al.* 1997).[54]

Given that "a majority of the documented occurrences of cave obligate amphipods ... have been in the project area," the FEIS and supporting resource reports are arbitrary because the agency failed to take a hard look at the effects on these rare species from using herbicides to treat invasive plants on high vulnerability karst. Neither the Draft ROD, FEIS, nor any of the supporting resource reports considered this important aspect of the issue before incorporating the use of herbicide treatments on invasive plants in the Selected Alternative.

V. FAILURE TO CONSIDER RECOMMENDATIONS FROM INTERAGENCY REVIEW TEAM'S PROJECT-LEVEL REVIEW VIOLATES TLMP.

The FEIS Summary states: '"Connectivity between large and medium old growth reserves (OGRs) was reviewed by an Interagency Old Growth Reserve Panel as required by the Forest Plan." [55] The 2018 Interagency Review Team (IRT) recommended a modification to a small Old Growth Reserve (OGR) lost from Value Comparison Unit (VCU) 5570 due to a congressionally-approved land exchange with replacement acres located in that VCU and adjacent VCU 5542.[56]

Our comments on the DEIS complained about the agency's failure to disclose and incorporate the IRT recommendations for this project.[57] In response, we learned that "[t]he Responsible Official decided to not amend the Forest Plan through this process to narrow the

[54] FEIS at 3-135.
[55] FEIS at vii.
[56] Pub. L. No. 115-31, Div. G, Section 431(a)(2) of the Consolidated Appropriations Act (May 5, 2017).
[57] *See* PR# 833 1634 at 14.

scope of analysis for this project."[58] This statement is arbitrary because as noted by the IRT "[a]n overall review of the Conservation Strategy is not necessary for a modification to an individual OGR [and can be] document[ed] through the NEPA process."[59] Although carrying out the recommended modification for this small reserve would result in an amendment to TLMP , we are unaware of any project approved after 1998 that did not amend the Conservation Strategy for a particular project area to some extent. Moreover, the U.S. Fish and Wildlife Service explained that it considered replacing the lost of old growth connectivity in VCU 5570 "to be the highest priority OGR adjustment."[60]

The 2016 TLMP requires the agency to "[d]esign projects to maintain landscape connectivity"[61] and "[d]uring the environmental analysis for [logging] projects" to evaluate whether there is "sufficient old-growth forest connectivity . . . ."[62] As the Forest Service explained in the FEIS for the 2016 TLMP, this is especially true on Prince of Wales Island:

> As development continues through timber harvest and associated activities such as road building, and community expansion, particularly in areas where extensive development has already occurred (i.e., Prince of Wales Island), maintaining connectivity and roadless refugia will become increasingly important, particularly for wide-ranging species whose distribution depends on some level of connectivity across the landscape.[63]

Appendix K to TLMP specifies the IRT process for project-level review. Appendix K recognizes the need for a project level review when "[a]ctions are proposed within the [Old Growth Reserve] that will reduce the integrity of the old-growth habitat in the OGR" and when "[t]he OGR will be affected by a land conveyance."[64] Replacing the lands in adjacent VCU 5542 will provide important habitat connectivity between Sarkar/Honker Large OGR and scattered outer islands to the west. The address the IRT's

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[58] FEIS, App. D at D-63.
[59] PR# 833 0903 at 7.
[60] *See* FEIS, App. D at D-105.
[61] 2016 TLMP at 4-87 (WILD.VI.A.).
[62] 2016 TLMP at 4-87 (WILD.VI.A.2).
[63] 2016 Forest Plan FEIS at 3-217.
[64] *Id.*, Appendix Kat K-1, 2.

recommendation to replace the lost of old growth connectivity in VC U 5570 is arbitrary and inconsistent with the 2016 Tongass Plan

VI. FOREST SERVICE VIOLATES NEPA BY FAILING TO USE HIGH QUALITY INFORMATION IN FEIS.

In our DEIS comments,[65] SEACC pointed out how the DEIS explanation of the Niblack and Bokan Mountain prospects was incomplete, inaccurate , and confusing. Our comments referenced existing agency documents and documents readily available on the State of Alaska's Large Mine Permit website. The discussion in the socioeconomic section of the FEIS,[66] however, completely ignores our comments and the cited information. Putting such unsubstantiated claims in official government documents lends a notion of undeserved credibility to these statements. The Forest Service is required to insure that whatever information is disclosed in the FEIS is of high quality and accurate. *See* 40 C.F.R. 1500.l(b); 1506.5(a).

Objectors request adding the following statement to the FEIS to address this matter:

> This FEIS includes certain statements that may be deemed "forward-looking statements." All statements in this FEIS, other than statement of historical facts, that address future financing and/or business acquisition activities, timelines, events or developments that the Forest Service expects, are forward looking statements. Although the Forest Service believes the expectations expressed in such forward-looking statements are based on reasonable assumptions, such statements are not guarantees of future performance or results and actual results or developments may differ materially from those in forward-looking statements. The Forest Service has assumed that these mines will in the near future be able to obtain interim financing and sufficient additional financing to actually create a single job. The Forest Service has also assumed that there will be no material adverse findings in the upcoming expected comprehensive due diligence reviews of reality for either of the prospects. Factors that could cause actual results to differ materially from those stated in the FEIS include: Bokan and Niblack's decades-long inability to raise sufficient funds to move forward; resistance to or non-compliance by the owners or key shareholders with the existing agreements; the emergence of alternative superior metallurgy and mineral separation technologies; unexpected transaction costs or other deal completion setbacks; the availability and procurement of any

[65] See PR # 833 1634 at 14-15.
[66] *Id.* at 3-300.

required interim financing that may be required; and general economic, market or business conditions.

Thank you for your careful consideration of these objections. We look forward to your response.

Best Regards,

Buck Lindekugel	Pam Miller
Grassroots Attorney	IPEN Co-Chair & Executive Director
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Report on anticipated impacts of aerially applied herbicide on karst areas on Long Island, Alaska.

Thomas J. Aley. June 28, 2005.

This report is prepared to comply with AK R RCP Rule 26 which requires that certain information be included in a written report signed and prepared by an expert witness.

Background Information and Experience

My naine is Thomas J. Aley. I am President of the Ozark Underground Laboratory, Inc. My office is at 1572 Aley Lane, Protem, MO 65733. The phone is 417-785-4289.

I hold B.S. and M.S. degrees in forestry from the University of California at Berkeley. .I am a licensed Professional Geologist in the states of Arkansas, Kentucky, and Alabama, and am a Registered Geologist in the state of Missouri. I am also a Certified Forester, certified by the Society of American Foresters, and a Professional Hydrogeologist certified by the American Institute of Hydrology. The bulk ofmy practice over the last 40 years has dealt with water and land use issues in karst landscapes with special emphasis on forested landscapes. A current copy of my resume, including a list of publications, is attached to this report as Attachment 1.

From 1966 to 1973 I was employed by the United States Forest Service as a hydrologist on the Mark Twain National Forest in Missouri. My principal duty was to direct study investigations on the Hurricane Creek Barometer Watershed. Approximately 20 barometer watersheds were established on National Forests across the nation to study the impacts of National Forest land management activities on water resources. The Hurricane Creek Barometer Watershed was established as the national type-example for karst areas. Results from this work have subsequently been used on many national forests including the Tongass National Forest in Alaska.

My work on the Hurricane Creek study included developing methods useful for tracing underground water flows in karst landscapes. Such tracing work, most commonly conducted with fluorescent tracer dyes, is critical to understanding where and how land management activities in particular areas will impact groundwater resources, springs, and spring-fed streams. As a part of my work on the Hurricane Creek study I served on a Forest Service panel to assess the off-target impacts of aerial application of herbicides on the National Forests in Missouri. Essentially all of these national forest lands are in karst regions.

I anticipate that my testimony will include some references to the Hurricane Creek Barometer Watershed studies and the relevance of that work and my experience to the potential use of aerially applied herbicides on Long Island.

Exhibit 3

3555

In 1973 I began full-time employment with the Ozark Underground Laboratory, a consulting and contract studies firm that I founded. Much of my work since 1973 has dealt with the subsurface movement of water and contaminants in karst landscapes. I have conducted this work throughout the United States and in several foreign countries.

Attachment 2 is a paper by Aley and Halterman (1982) from a symposium proceedings entitled "A conceptual characterization of the subsurface movement of toxic chemicals in soluble rock lands." It provides a discussion of the issue for an audience consisting largely of land and resource managers and should be useful to the Hearing Officer. I anticipate that issues discussed in this paper will be the topic of some of my testimony.

I have directed or been involved with a number of groundwater tracing investigations on Prince of Wales, Tuxekan, Heceta, Kosciusko, and Chichagof Islands. I have also conducted karst work on Dall and Baker Islands. Groundwater tracing work on these islands has clearly and consistently demonstrated that the karst groundwater systems of the region are extremely open to the entry and rapid subsurface transport of potential water contaminants. These contaminants would include aerially applied herbicides.

Issue 1. The applicant failed to produce a technically credible characterization of karst and karst groundwater conditions on Long Island. As a result the applicant has failed to develop information essential for answering a specific information request from the DEC.

DEC sent Klukwan Inc., Long Island Trust a letter dated July 30, 2004 relating to deficiencies in the permit application to apply herbicides on Long Island. DEC requested the following information:

"A discussion about the soil types and Karst topography is also needed. Explain what factors you considered and what assurances we have that the chemicals will not enter any underground streams supported by this topography?"

In response to the DEC request, the applicant submitted a document entitled "Reconnaissance Survey of Groundwater Conditions on Northern Long Island, Alaska" authored by Thomas O'Donnell and dated December 21, 2004. In subsequent discussions we will call this report and its appendices the O'Donnell report.

O'Donnell states (page 3):

"The American Society for Testing Materials has established general criteria for determining and classifying karst terrains based on geomorphologic and hydrological conditions. (ASTM D5717.95el) These are based onfeatures that can often be determined by reconnaissance level investigations using available published technical reports and maps. Features used to classify specific karst areas include: bedrock type, depth to bedrock or soil thic kness, topography, surface and subsurface ydrology, spring

chemistry, distribution, landscape position, and type of surface and subsurface karst features. "

Later (p. 4) O'Donnell states:

"Both the ASTM and Forest Service criteria were used to design the investigation that is reported in this document. "

I served on the committee that wrote this ASTM document and it clearly does not do what O'Donnell claims; it is also not listed in his references. The title of the document is: "Standard Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers". A copy of this ASTM standard guide is attached as Attachment 3.

Contrary to what O'Donnell states, ASTM Standard D 5717 does not establish general criteria for determining and classifying karst terrains based on geomorphologic and hydrological conditions. Contrary to what O'Donnell states, ASTM Standard D 5717 does not classify specific karst areas based on features which include: bedrock type, depth to bedrock or soil thickness, topography, surface and subsurface hydrology, spring chemistry, distribution, landscape position, and type of surface and subsurface karst features. The "Introduction" to ASTM Standard D 5717 states:

"This guide for the design of ground-water monitoring systems in karst and fractured-rock aquifers promotes the design and implementation of accurate and reliable monitoring systems in those settings where the hydrogeologic characteristics depart significantly from the characteristics of porous media. "

ASTM Standard D 5717 would have been appropriate for O'Donnell's work ifhe had planned a monitoring system to detect and quantify herbicides in and discharging from the karst groundwater system on Long Island. No such monitoring activities were proposed in the O'Donnell report or by the applicant for this spray project. While almost any document might be of some tangential benefit in almost any project, it is clear that the statement by O'Donnell that he used the ASTM criteria in designing his investigation is, at best, a gross overstatement of the relevance of this statement to the work actually conducted by- 0 'Donnell.

It is equally clear that O'Donnell's claim that he used U.S. Forest Service criteria for designing h.is investigation is unsupported by the report of his investigation. While he notes (page 4) that the Forest Service has established and published a karst vulnerability classification system that recognizes areas with low, moderate, d high vulnerability, he made no effort to determine the karst vulnerability classes existing in the proposed spray area. The karst vulnerability classes are critical to the evaluation of land management activities on karst resources and the karst groundwater system. He also made only trivial efforts to identify and characterize features (such as caves, springs, and the thickness of the epikarstic zone) that are diagnostic of the various vulnerability classes. My conclusions are based on the O'Donnell report and my familiarity with the Forest Service karst vulnerability system for the Tongass National Forest. I was involved with the initial development of these standards and, in 2002, I was a member of the Karst Review Panel which reviewed the standards and their implementation (Karst Review Panel, 2002).

DEC asked the spray applicant to explain what factors were considered and what assurances there were that the chemicals would not enter any underground streams supported by this topography. The karst vulnerability class (High, Moderate, or Low) is a key factor needed for a credible karst assessment and for developing credible assurances about the extent to which applied herbicides would enter underground streams.

O'Donnell reports (page 5) that there were two primary components to his investigation, and that his investigations were modeled after programs for inventory of karst terrains that had been conducted on the Tongass National Forest and on coastal forests in northern British Columbia. His reference for karst inventories in British Columbia was Stokes and Griffiths (2000). Once again, the nature and extent of the O'Donnell .work was extremely superficial and inconsistent with the programs that he references. As noted earlier, I am familiar with the Tongass National Forest program. I am also familiar with the program used in British Columbia and was one of the technical reviewers for the cited Stokes and Griffiths (2000) document. I also worked in the field with Stokes and Griffiths and results of that work are included in Stokes and Griffiths (2000).

O'Donnell reports (page 5) that he conducted a literature search and reviewed the information. He also reports (page 9) that he conducted a one-day field survey that consisted of a fly-over and an on-ground inspection of the Long Island Trust Property. He reportedly made site inspections at 14 locations and additional observations along the roads. There is no indication that he made any stereoscopic study of aerial photos of the island. Such studies of karst areas in Southeast Alaska routinely identify numerous major karst features such as large sinkholes and likely areas for finding large insurgences. Such air photo studies often provide insight into the degree ofkarst vulnerability. The aerial photos are routinely superior to fly-overs in identifying karst features and karst vulnerability.

Based upon my experience with karst assessments on Prince of Wales, Tuxekan, Heceta, Kosciusko, and Chichagoflslands, a credible karst assessment on Long Island would have required a minimum of approximately 20 man-days of fieldwork including three to five groundwater traces. In addition, the field personnel would have required training in karst vulnerability assessment work and in designing and conducting groundwater traces. Dye analysis work requires that samples be shipped to a laboratory experienced in conducting such work and capable of separating multiple tracer dyes in the same sample. A preliminary stereoscopic study of aerial photos is routinely done at the beginning of the project and then in the field throughout the period of fieldwork. This intensity of investigation is consistent with work done for the U.S. Forest Service on the Tongass National Forest and with work conducted in British Columbia as outlined in

Stokes and Griffiths (2000). This level of work would have enabled the applicant to answer the karst questions asked by DEC.

O'Donnell reports (page 10) that no sinkholes were identified during his inspection, yet his photo 1362 of a cave entrance appears to show that it is located in the bottom of a sinkhole. Under the Tongass karst classification system lands in the vicinity of this feature would be classed as high vulnerability regardless of whether or not this was a sinkhole.

Sinkholes provide extremely direct and open connections between the surface of the land and the underground streams that provide subsurface drainage for the karst. As a result, assessing the location and abundance of sinkholes on Long Island is essential to answering the DEC questions about herbicides reaching underground streams. Sinkholes are common to abundant on karst areas throughout Southeast Alaska. Based upon my experience it is essentially impossible for there not to be sinkholes in the karst areas on Long Island. The fact that O'Donnell did not identify any is a reflection of his superficial investigation rather than a credible characterization of the karst on Long Island.

O'Donnell reports (page 10) that surface epikarst features consisted of swales and shallow hummocky topography as shown in Photograph 1363. That photograph appears to show an elongated karst valley such as those commonly associated with high vulnerability karst lands. Based upon the very limited information and photos provided in the O'Donnell report it is clear to me that there are karst lands in the proposed spray area that would be classified as high vulnerability lands under the Tongass National Forest karst classification system.

On page 11 O'Donnell reports that iand on Long Island underlain predominantly by marble appears to be drained internally through permeable conduits formed by dissolution of the carbonate rock On page 17 he notes that perennial surface water features are not abundant and that this implies that a significant part of the annual average of 137 inches of rainfall leaves the island via underground flow. He also notes that water that infiltrates to the groundwater in karst areas will move rapidly to discharge points. These observations are fully consistent with a well developed and hydrologically integrated karst groundwater system capable of rapidly draining overlying and adjacent tributary lands and conveying the water rapidly through caves and karst groundwater conduits to springs which will be both inside and outside of the planned spray area. These are the s e conditions found in karst areas on nearby islands. These observations by O'Donnell and their routine relationship to rapid water movement into and through the karst groundwater system are inconsistent with O'Donnell's conclusion that the karst groundwater system will not be significantly impacted by the proposed herbicide application.

In summary, the assessment ofkarst in the O'Donnell report was extremely superficial. O'Donnell stated that his investigations were modeled or designed based upon ASTM Standard D 5717 and programs for inventory ofkarst terrains on the Tongass National Forest and on coastal forests in northern British Columbia. This contention is, at best, a misstatement apparently designed to give unwarranted authority and credibility to the work-which O'Donnell conducted. A technically credible inventory and assessment of the karst on Long Island was clearly needed to properly respond to the information request of DEC. O'Donnell identified relevant approaches, said that he used them, but essentially ignored them in the work that he conducted. Finally, O'Donnell's conclusion that the karst groundwater system will not be significantly impacted by the proposed herbicide application is not supported by credible information and is, in fact, inconsistent with information that O'Donnell provides in his report.

Issue 2. Based on work by O'Donnell, the DEC Decision Document (page 7) concludes that less than 1% of applied herbicide is expected to reach the soil surface of Long Island. Climatic conditions, the absence of permit stipulations prohibiting herbicide application prior to precipitation events, and characteristics of the herbicides make this conclusion unlikely and unreasonable.

The application rates of the two herbicides are to be 1.5 quarts per acre of Accord and 2 ounces per acre for Arsenal. Adjusting for the specific gravity of Accord (1.158) this equals 57.4 ounces of this herbicide per acre. Of the total herbicide mixture 3.4% of the herbicide to be applied will be Arsenal and 96.6% will be Accord.

It rains frequently, in appreciable quantities, and in all seasons in Southeast Alaska; that is why the area is classified as a temperate rainforest. Mean annual precipitation on Long Island is 137 inches per year (O'Donnell report). The DEC Decision Document states (page 7):

"Based on previous published accounts of the fate of Accord in similar application scenarios, the limited area of application, dilute solution concentrations, and dense vegetative growth, less than 1% ofapplied herbicide is expected to reach the soil surface of Long Island."

The above is not a credible statement for the following reasons:

Reason 1. The DEC Decision Document states that the application of Accord on Long Island represents a similar application scenario to the one reported in the literature by Newton et al.(1984) (see citation in O'Donnell report). This is not true. The estimate that less than 1% of the applied Accord will reach the forest floor is derived from a herbicide application in the Coast Range of Oregon. Summer rainfall in that portion of Oregon is infrequent and minimal whereas measurable rainfall on Long Island during the summer months occurs on more than half of the days. Rainfall washes herbicides off plant foliage and deposits it on the forest floor; the pesticide fact sheet on glyphosate in Appendix B of the O'Donnell report notes that glyphosate is highly water soluble. While the l% value might be applicable to the amount of herbicide reaching the forest floor at the time of herbicide application, the DEC failed to consider or evaluate the amount of herbicide that is washed off vegetation by the frequent precipitation events characteristic of the Long Island area. As a result, the estimate that less than 1% of the applied herbicide will reach the forest floor grossly under-estimates the total percentage of herbicide that will reach the forest floor.

Even during the period of the year when the herbicide would likely be applied it is more likely than not to rain on any particular day. Long Island receives about 2.5 times more precipitation per year than does Juneau, yet measurable precipitation occurs in Juneau on 53% of the days in June, 55% of the days in July, 58% of the days in August, and 67% of the days in September (van der Leeden et al., 1991). Data for weather stations nearer Long Island would be expected to show even higher percentages of days with measurable precipitation.

Reason 2. The DEC Decision Document (pages 20 and 21) lists pennit stipulations and pennit-specific conditions. There is no stipulation or pennit-specific condition that would prohibit the application of the herbicides on wet vegetation or shortly before precipitation events or, for that matter, even during rainfall events so long as the helicopter could fly safely. The label directions on the two herbicides do not prohibit applying the herbicide to wet plant surfaces or to plants prior to anticipated precipitation. The label for Accord recognizes, under the heading of"General Information," that rainfall after herbicide application can wash the chemical off the foliage. More specifically, the label notes that precipitation occurring within 6 hours after application may reduce effectiveness, and that heavy rainfall within 2 hours after application may wash the chemical off the foliage and a repeat treatment may be required (see also AR 0134). A case history example later in this report illustrates the extent of karst groundwater contamination and transport that can occur when precipitation follows even very localized herbicide applications.

Helicopter standby time waiting for a period when rainfall is unlikely for several days after spraying can substantially add to the cost of the spray project and to general logistical difficulties. Since there are no specific constraints in the permit nor the label requirements that relate to precipitation events it is likely that spraying will be conducted at a time when it is hoped that the foliage will absorb enough herbicide to cause an effective kill before remaining herbicide is washed off the foliage and onto the forest floor. It is unlikely and unreasonable to expect that this approach will result in less than 1% of the applied herbicide reaching the forest floor.

Reason 3. Approximately 3.4% of the herbicide applied to the vegetation will be Imazapyr (Arsenal). Label information and the pesticide fact sheet in Appendix B of the O'Donnell report state that this herbicide is water soluble and highly mobile. The pesticide fact sheet for Imazapyr in Appendix B of the O'Donnell report states that the halflife oflmazapyr on plants ranges from 12 to 40 days. The chance that one or more precipitation events capable of washing more than half of this water soluble and highly mobile herbicide off plants and onto·the forest floor is very high. Based upon the precipitation patterns of the area DEC should assume that more than half of the Imazapyr applied under the permit will reach the forest floor. Cautionary label information for this herbicide. under the heading of "Environmental Hazards" (AR page 0128) states that this herbicide is extremely phytotoxic at extremely low concentrations. The statement in the

DEC decision document that less than l % of the applied herbicide will reach the forest floor is not credible with respect to the combined mixture of Accord and Arsenal, and is dramatically in error with respect to Arsenal, which is the more phytotoxic of the two herbicides. The O'Donnell report basically argues that the amounts of herbicide reaching the forest floor are so small as to be of no consequence. This is not the case in a temperate rainforest, and is especially not the case with Imazapyr.

Issue 3. The O'Donnell report and the DEC decision document inaccurately characterize the karst groundwater systems of Southeast Alaska and the ability of herbicides to enter and be rapidly transported through these systems to springs and spring-fed streams.

Reason 1. The DEC decision document (page 8) incorrectly states that Imazapyr has a half-life of no more than 2 days in water. This is factually incorrect. Note that page 5 of the DEC decision document, under the heading "Imazapyr", states that this herbicide will quickly undergo photodegradation in aqueous solutions with a half-life of only two days. Photodegradation means degradation in the presence of light. There is no sunlight present in groundwater systems, including karst groundwater systems. Photodegradation is also appreciably reduced in the shade beneath the tree canopy. As a result, except for herbicide in water solutions in direct sunlight, there are no documents of record indicating a decomposition rate for Imazapyr in water solutions. In a karst aquifer any degradation of Imazapyr will be primarily or perhaps exclusively due to microbial metabolism, and such herbicide metabolism rates will be orders of magnitude slower than in soils where there are larger microbial populations. The fact that there are orders of magnitude larger microbial populations in the soil than in the karst groundwater system is well known to biologists who routinely work with caves.

Reason 2. The DEC incorrectly asserts that typical groundwater residence times (even in karst systems) are usually much longer than a month or two, which should provide enough time for herbicide degradation before re-emergence. This assertion can be found on page 16 of the DEC responsiveness summary. The same assertion is found as reason 4 on page 9 of the DEC decision document.

While I agree that typical groundwater residence times in non-karst aquifers are usually longer than a month or two, this is clearly not the case for karst areas in general or for conditions typical of Southeastern Alaska. The above statement by the DEC is not supported by technical karst hydrology literature or by actual results from studies in Southeast Alaska. No technical source is given for this speculative comment and there are no references at all dealing with karst cited in the DEC decision documents.

Typical groundwater residence time in karst aquifers of Southeast Alaska is only a few days. This has been demonstrated in numerous groundwater tracing studies in Southeast Alaska. Attachment 4 summarizes dye trace lengths, gradients, and estimated mean velocities for the first arrival of tracer dyes from 18 ground\vater"traces conducted during a study on Prince of Wales Island. These traces were conducted during late summer and early fall conditions in 2003 when conditions were typical of that time of year. The report from which this table is excerpted also notes that groundwater velocities can be an order of magnitude greater under wetter conditions. The applicant did not conduct any groundwater traces on Long Island and did not present any data relative to groundwater traces on that island. Given the lack of any specific data to the contrary, typical groundwater residence times in the area proposed for herbicide application on Long Island must be assumed to be similar to those on other islands with extensive karst in this part of the state and thus only a few days.

Reason 3. DEC fails to recognize that herbicides are commonly found in the waters ofkarst springs when those pesticides are sprayed on lands that contribute water to the karst groundwater system. The DEC incorrectly concludes that typical groundwater residence times are long enough to provide for herbicide degradation before re-emergence.

The US Geological Survey (USGS, 2002) (Attachment 5) publication "Pesticides and nutrients in karst springs in the Green River Basin, Kentucky, May-September" indicates that groundwater detention times and degradation rates in karst are not sufficient to prevent the discharge of measurable quantities of herbicides. Eight karst springs were monitored during the study period. The herbicide atrazine was detected in 100% of the sampled springs and the herbicide Simazine was detected in 93% of the springs. These data run counter to the DEC assertion that:

" ...typical groundwater residence times (even in karst systems) are usually much longer than a month or n-vo, which should provide enough timefor herbicide degradation before re-emergence ... ".

The USGS publication states:

"Ground water and springs in the Green River Basin potentially are vulnerable to increased concentrations of pesticides and nitrates associated with agricultural activities, such as pesticides and nitrates, because of the presence of karst topography. The karst topography can allow rapid recharge of flow through fractures in rock and solutional conduits, providing little opportunity for natural filtering to occur. Understanding the extent and potential severity of ground-water contamination in karst areas is therefore crucial to protecting"the public and water resources in the Green River Basin. "

The USGS (2002) publication clearly demonstrates that herbicides are not effectively detained and degraded in the soil overlying karst units, but instead move through these soils and into karst aquifers and their receiving springs. As a Professional Geologist licensed in the state of Kentucky I can verify that the soils in the Green River Basin are deeper and finer textured than almost all soils that I have seen in karst areas of Southeast Alaska. As a result, the soils in the Green River Basin of Kentucky should be more effective in detaining and degrading herbicides than the soils existing in Southeast Alaska. Furthermore, annual precipitation in the Green River Basin is on the order of 45 to 50 inches per year whereas O'Donnell (2004) reports that the annual precipitation on Long Island is about 137 inches per year. In addition, evapotranspiration rates in Kentucky are far greater than on Long Island, Alaska. Movement of herbicides from surfaces (including bare soil, rock, or vegetation) into and through karst soils would be expected to increase as precipitation amounts increase and as evapotranspiration rates decrease.

Reason 4. DEC has not adequately recognized that herbicide degradation to harmless compounds is much slower in groundwater systems than in soils. This is well established in the technical literature. One of the primary reasons for the slower rates in groundwater than in soils is the orders of magnitude lower levels of microbial activity in groundwater as compared with soils. Toe Decision Document dated March 7, 2005 by the Division of Environmental Health provides some statements on degradation rates in soils but fails to consider the ineffectively low degradation rates of herbicides in groundwater. Page 1 of the Decision Document of March 7, 2005 states:

"2. Glyphosate is strongly adsorbed to soil and relatively immobile, preventing excessive leaching or uptake by non-target plants. The half-life averages two months. Glyphosate is also degraded by rapid microbial action.

"3. Of the herbicides commonly used in forest applications, imazapyr is one of the more persistent, depending on the soil type. The half-lives of most other forest herbicides are generally 2 to 5 weeks (Spence, 1996). Other studies show the persistence of imazapyr in soil is highly variable and reported soil half lives range from about 5 days to 17 months, depending on factors such as temperature, pH, aeration, organic matter, and soil depth. The most influential factor in the persistence of imazapyr in soil, however, appears to be microbial activity. "

Given the rates of water movement through the karst groundwater systems of southeast Alaska it is c_learto me.that there will be only minor degradation of any of the herbicides that enter the groundwater system. This is the case even if the half life values given for soils were applicable (which they are not) to degradation within the groundwater system.

Reason 5. The O'Donnell report and the DEC decision document contend that most of the herbicides reaching the forest floor would be retained or destroyed in the soil prior to entry into the karst groundwater system. This contention fails to recognize that water and contaminant migration from the forest floor into the underlying karst conduits during precipitation events is extremely rapid, and as a result the soils will not provide effective adsorption and degradation of the herbicides. The USGS publication discussed earlier makes this point and this is the reason that herbicides are commonly found in the water of karst springs that drain areas which have received herbicide applications.

Karst springs in Southeast Alaska respond within hours to precipitation events. Precipitation of an inch or more (and sometimes less) routinely result in several-fold flow rate increases at springs. Dye tracing results in karst areas demonstrate that the increased flow in springs associated with precipitation events is due predominantly to the precipitation which fell during the rainfall event rather than being due to water displacement in a saturated aquifer.

Reason 6. The DEC decision document contends that most contamination of karst aquifers is from point sources. From this they incorrectly infer that non-point source contamination is not a problem for karst aquifers and thus aerially applied herbicides will not significantly impact the karst aquifer on Long Island.

Karst aquifers are open to both point and non-point sources of contamination. Many of the non-point source contaminants enter the groundwater system through localized flow routes called discrete recharge zones. In cut-over areas these are often features such as old root channels or other types of macropores. The DEC decision document does not list any references specific to karst.

The USGS document enclosed as Attachment 5 deals with herbicides in karst springs. These herbicides entered primarily from non-point source applications. In a karst setting it is incorrect to assume or infer that the only groundwater contamination of concern will be that associated with point sources.

Case History Study

In addition to the three specific issues discussed above, I expect to testify about a groundwater tracing study I did in a karst area of Missouri associated with powerline spraying with herbicides that did damage to plants in a nearby greenhouse. The water used in the greenhouse came from a spring. The powerline right-of-way had a width of about 30 feet and had been sprayed by the utility company. The herbicide that was used is not known to me. The herbicide application was probably ground-based. Attachment 6 is a report which I prepared on this study.

The first spraying of the powerline was done on July 22, -1994. It rained after the spraying and the line was reportedly re-sprayed the next week. Water from a spring in the area was used as the irrigation water for the greenhouse, and the use of this water caused extensive plant damage and plant death in the greenhouse.

I did two dye traces associated with the powerline during January 1998. One trace used 0.1 pounds of eosine dye mixture containing 75% dye equivalent in 0.7 quarts of water. This dye mixture was poured on the ground in a small dry stream channel in the spray zone. For the other trace I introduced 0.25 pounds of liquid rhodamine WT dye mixture; this mixture contained 20% dye equivalent. This was introduced into the flow of a small stream that sank into the groundwater system within 300 feet of the dye introduction point.

Eosine dye from the powerline was detected at four springs in the area and rhodamine WT was detected at three of these springs. The one spring that received only eosine dye was Powerline Spring, and the rhodamine WT was introduced downstream of this spring. Both dyes were detected in both activated carbon and water samples at the spring supplying the greenhouse and in both water and activated carbon samples from the other 2 (or in one case 3) springs.

The straight-line travel distance for the eosine trace from the point of dye placement to the greenhouse spring was about 2,900 feet; the distance for the rhodamine WT trace was about 2,700 feet. A water sample collected at the greenhouse less than 20 hours after the introduction of the dyes contained both of the dyes. Only a small portion of the area that contributes water to the greenhouse spring was sprayed.

The greenhouse case is relevant to the issue at hand for several reasons. It demonstrates that spraying only a small portion of a spring's recharge area with herbicide can degrade water quality to the extent that it banns or kills greenhouse plants. This case demonstrates that, contrary to assertions made in the DEC documents, herbicide detention and degradation in karst soils and in karst aquifers feeding springs did not prevent the migration of herbicide in quantities sufficient to hann or kill plants. The dye tracing associated with the case demonstrated that water and contaminants (in this case dyes) can readily move into and through karst soils and the karst aquifer. Finally, the case demo:Qstrates that precipitation following herbicide application can flush herbicides from plant and other surfaces into and through karst aquifers feeding springs.

Other Required Information

Compensation to be Paid for Study and Testimony

My charge rate is $110.00 per hour regardless of the nature of the work. This is the same rate now charged to all clients except for those where the project began when a lower charge rate was in force. Expenses are billed at cost plus 5%.

Testimony in the Last Four Years

In the last four years I have given depositions and/or testified in the following matters:

Erwin Anthony Earl, Plaintiffv. City of Springfield, Defendant. US. District Court for the Western District of Missouri. Case No. 01-3213-CV-S-4. Deposition given in late 2002. Issue involved claimed degradation of water quality in Rader Spring due to sewage treatment plant effluents from City of Springfield. My work included groundwater tracing. Case was dropped by plaintiff. I was an expert for the City of Springfield.

Julian E. Holmes et al. plaintiffs v. McCartney Construction et al. Civil Action CV-99-362 in the Circuit Court of Talladega County, Alabama. Deposition given July, 2001; trial testimony was in late September and early October 2002 in Talladega County Circuit Court, Alabama. I was an expert for the plaintiff {Holmes). Issue involved catastrophic formation of many new sinkholes on property of Holmes caused by heavy pumping of the

McCartney Quarry. A former perennial spring ceased flowing due to quarry pumping. Dye tracing showed rapid karst groundwater flow. Plaintiff won monetary judgment.

Combined cases:
Corra Hutto, and Dorothy Parham v. McCartney Construction Company, et al. Circuit Court of Talladega County, Alabama. Civil Action No. CV02-471
Edward Hutto v. McCartney Construction Company et al. Circuit Court of Talladega County, Alabama. Civil Action CV00-330.
John Shaddix v. McCartney Construction Company et al. Circuit Court of Talladega County, Alabama. Civil Action CV00-287.
I was the expert for all plaintiffs. Issues involved sinkhole formation and land subsidence in a karst area due to quarry pumping oflarge volumes of groundwater. Settled after my deposition, settlement terms not released.

The Boeing Company v. Affiliated FM Insurance Co. et al. Superior Court of the State of Washington for King County. No. 99-2-03873-SEA. Expert for The Boeing Company (plaintiff). I gave a deposition in Seattle on January, 2002. My work involved the reasonableness of actions by Boeing to discover, evaluate, monitor, and remediate TCE and some other contaminants in groundwater at the Boeing plant in Wichita, Kansas. The case was settled after my deposition, terms not disclosed.

R.G. Edmondson, trustee of the Jewell Edmondson Testamentary Trust v. Doug Edwards and Sandy Edwards. Circuit Court of Barry Co., Mo. CV 101-452CC: Expert for Edmondson (plaintiff). Defendant had constructed a large pond downstream of a karst spring. The pond leaked into the karst groundwater system thus decreasing (and sometimes eliminating) natural ater flow to the Edmondson property. Testified at trial, judgment to plaintiff.

Mike Davis, et al., Plaintiffs v. Hartson Aggregates Southeast, Inc., et al. Civil Action No. CV 2002-85 in the Circuit Court for Lee County, Alabama. The issue involved off-site impacts of quarry pumping in an area where fractured non-karst rocks separated karst units. Resulting damage included sinkhole formation, subsidence of a county highway, and loss of water supply to a former perennial spring in an Opelika City park. I was expert for plaintiffs and gave three depositions and testified in court. Judgment for plaintiffs. 2004.

Basis and Reasons for Opinions

In addition to information previously provided and attached to this report my professional opinions are based upon my education, over 40 years of experience, and upon technical literature.

Purpose of Testimony

The purpose ofmy testimony is to demonstrate that the DEC decision document is severely flawed relative to issues involving karst lands and the likely movement of water and herbicide in those lands. Many of these flaws are a direct result of flaws, omissions, and incorrect statements in the O'Donnell report. The DEC has placed unwarranted reliance on the O'Donnell report.

References

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Aley, Tom and Danny Halterman. 1982. A conceptual characterization of the subsurface movement of toxic chemicals in soluble rock lands. IN: Wilson, Ronald C. and Julian J. Lewis. National Cave Management Symposia Proceedings. Pp. 77-80.

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Signature

I certify that I prepared this report and that it accurately reflects my professional conclusions and opinions.

Thomas Aley, President
Ozark Underground Laboratory, Inc.

Attachments

1. Resume of Thomas Aley
2. Aley and Halterman. "A conceptual characterization of the subsurface movement oJ toxic chemicals in soluble rock lands."
3. ASTM StandardD-5717. 1995.
4. Table . Summary of Dye Trace Lengths, Gradients, and Estimated Mean Velocities 1 the First Arrival of Tracer Dyes. From Aley and Moss (2004).
5. USGS. 2002. "Pesticides and nutrients in karst springs in the Green River Basin, Kentucky, May-September 2001".
6. Groundwater tracing study of Stupperich Spring !ffid vicinity.

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Resume of Thomas Aley

PERSONAL DATA

Born September 8, 1938 in Steubenville, Ohio. U.S. Citizen. Married, two adult children.

EDUCATION

University of California, Berkeley. B.S. in Forestry (1960).

University of California, Berkeley. M.S. in Forestry with emphasis in forest influences and wildland hydrology. (1962).

University of California, Berkeley . Department of Geography (1962-1963); emphasis in hydrology and geology.

University of Arizona, Tucson. Department of Watershed Management (1963-1964); emphasis in wildland hydrology.

Southern Illinois University, Carbondale. Department of Geography (1972-1973). Emphasis in hydrology and geology.

PROFESSIONAL CERTIFICATION & REGISTRATION

Professional Hydrogeologist, Certificate Number 179, American Institute of Hydrology, Board of Registration. Granted 1983.

Certified Forester, Society of American Foresters. Granted 1996.

Professional Geologist, State of Arkansas Registration Number 1646. Issued 1991.

Professional Geologist, State ofKentucky Registration Number 1541. Issued 1994.

Registered Geologist; State of Missouri Registration Number 0989. Issued 1998.

Professional Geologist, State of Alabama Registration Number 1089. Issued 2003 .

PROFESSIONAL SOCIETY MEMBERSHIPS

American Institute of Hydrology
Association of Ground Water Scientists and Engineers
Society of American Foresters
Missouri Consulting Foresters Association
National Speleological Society

HONORS AND AWARDS

1960. Pack Prize in Forestry. University of California.
1961. Membership in Xi Sigma Pi, honorary forestry society.

1972. Award for outstanding performance, United States Forest Service.
1972. U.S. Forest Service nominee for the American Motors Conservation Award.
1973. Lester B. Dill Award for significant contributions to speleology. Mississippi Valley-Ozark Region of the National Speleological Society.
1977. Chairman's Conservation Award. Mississippi Valley-Ozark Region of the National Speleological Society.
1979. J Harlan Bretz Award for outstanding contributions to the study of speleology in the state of Missouri. Missouri Speleological Survey.
1981. Outstanding Service to Education Award. Phi Delta Kappa honorary educational fraternity for southwest Missouri.
1981. Fellow. National Speleological Society.
1988. In The Name of Science Award. Springfield, Missouri Public Schools. In recognition of outstanding service and dedication to science.

EMPLOYMENT HISTORY

1973 to Present. Director and President, Ozark Underground Laboratory, Protem, Missouri. Conducts or directs consulting and contract studies in hydrogeology, cave and karst related issues, and natural resource management ofkarst regions.

1966 to 1973. Hydrologist, United States Forest Service. Winona, Missouri and Springfield, Missouri. Directed the Hurricane Creek Barometer Watershed study, which assessed the interactions of land use and ground water hydrology in a forested karst area. Directed Grey Hollow study. Conducted "trouble shooting work" in Missouri, Arkansas, Wisconsin, Utah, Illinois, and Indiana. Left government service as GS-12.

1964 to 1965. Chief Hydrologist, Toups Engineering, Inc., Santa Ana, California. Duties included basic data collection and analysis for plaintiffs in Santa Ana Basin adjudication and similar work for defendants in San Gabriel Basin adjudication; these were both ground water basin adjudication· suits. Directed technical work on ground water basin management and artificial recharge.

1963 to 1964. Teaching Assistant, Department of Watershed Management, University of Arizona, Tucson. Aerial photogrammetry and photo interpretation.

1963. Researcher, grant from Office of Naval Research, U.S. Navy, through Department of Geography, University of California, Berkeley. Conducted field studies on the origin and hydrology of caves in Jamaica, Haiti, and the Dominican Republic. Responsible for all field work. Work resulted in 3 publications.

1960 to 1963. Teaching Assistant and Research Assistant, School of Forestry, University of California, Berkeley. Teaching in aerial photogramrnetry, photo interpretation, and forest influences. Research assistant in the same fields.

SUMMARY OF EXPERIENCE

39 years of professional experience in ground water and surface water hydrology, pollution control investigations, and land management issues with particular emphasis on soluble rock landscapes. The.following projects are representative examples.

1. Hydrologic studies for land management and spring protection with particular emphasis on soluble rock regions. Numerous studies of this type have been conducted for local, state, and federal agencies in Missouri, Arkansas, Alabama, Kentucky, Illinois; Tennessee, Alaska, and Wyoming.

2. Expert witness testimony on pollution p·otential of underground injection of hazardous wastes into deep-lying soluble rocks in Oklahoma.

3. Expert witness testimony in ground water and surface water hydrology in Missouri, Arkansas, Oklahoma, Kansas, California, Alabama, Maryland, and Indiana.

4. Expert witness testimony on riverbank stability problems in Missouri before U.S. Senate Committees at request of Senator John Danforth of Missouri.

5. Member of 6-member review panel on . the adequacy of testing to determine radionuclide migration from a radioactive waste disposal site at the Idaho National Engineering Laboratory, Idaho. Served as the only hydrogeologist on the panel.

6. Member of 6-member expert hydrogeology panel on hydrological issues associated with the St. Louis Airport Radioactive Waste Site.

7. Chairman of a 4-member "blue ribbon" panel established by the U.S. Forest Service to assess the significance of cave and karst resources in southeastern Alaska. The panel also assessed the extent to which land management activities were adversely impacting the resources.

8. Hydrologic consultant to St. Charles County, Missouri on clean-up of radioactive wastes at Weldon Spring Site, a former Atomic Energy Commission processing facility. Advised on actions to protect county well field from radioactive contaminants dumped in an abandoned quarry.

9. Ground water tracing in soluble rock landscapes, and delineation of recharge areas for spring systems. Work conducted in Missouri, Arkansas, Oklahoma, Indiana, Illinois, Kentucky, Tennessee, Alabama, Florida, Georgia, Texas, Maryland, Pennsylvania, New York, West Virginia, Arizona, Oregon, California, Wyoming, and Alaska. Ground water tracing in fractured rock landscapes in New Hampshire, Alabama, New Mexico, Minnesota, Idaho, Utah, and Washington. Ground water tracing in unconsolidated geologic units in New York, Massachusetts, Florida, North Carolina, South Dakota, Missouri, Arkansas, California, Oregon, Washington, Alaska, and British Columbia (Canada).

10. Hydrogeologic investigations of groundwater impacts from pipeline corridors. Missouri, Oklahoma, and Texas.

11. Ground water tracing investigations at mines in West Virginia, Pennsylvania, Missouri, Utah, Colorado, Montana, Irian Jaya Indonesia, and Peru.

12. Hydrologic investigations to determine sources of pollutants which caused fish kills at commercial fish farms in Missouri and Arkansas.

13. Hydrogeologic site investigations (and sometimes testimony) on municipal landfills with emphasis on site suitability and probability of ground water contamination. 21 sites in Arkansas, Missouri, Wisconsin, and Alabama.

14. Hazardous waste remediation investigations with emphasis on hydrogeology. Sites in Missouri, Arkansas, Kentucky, Pennsylvania, Maryland, Alabama, Tennessee, and California. Second opinion review of projects in Missouri, Kansas, and New York.

15. Impacts of food processing wastes on surface and ground water quality. Various projects in Arkansas and Missouri.

16. Hydrologic investigations of petroleum pollution of wells. Multiple sites in Missouri, Arkansas, and North Carolina.

17. Assessment of the hydrologic impacts of proposed geothermal energy development on the Santa Clara Indian Reservation, New Mexico.

18. Investigations on the extent and sources of sewage contamination in about. 100 springs at Eureka Springs, Arkansas. Work involved the delineation of recharge areas for most of these springs and the identification of sewer line segments which had the greatest leakage problems.

19. Hydrogeologic hazard area mapping for proposed sewer line corridors in a sinkhole plain area south of Mammoth Cave, Kentucky. Work included hydrologic recommendations for minimizing exfiltration and monitoring strategies.

20. Hydrogeologic mapping of Greene County, Missouri to identify areas where sinkhole flooding and serious ground water contamination could result from land development.

21. Assessment of impacts of proposed highways on springs, caves, and endangered cave-dwelling species, Arkansas, Missouri, Indiana, Virginia, and West Virginia. Similar work for airports in Missouri and Arkansas, and for coal-fired power plants in Missouri and Arkansas.

22. Identification and delineation of rare, threatened, and endangered animal species' habitats in caves and ground water systems. Studies in Arkansas, Missouri, Oklahoma, Tennessee, Alabama, and Illinois.

23. Health and safety assessment of Harrison's Crystal Cave, Barbados.

24. Health and safety assessment of natural radiation as encountered in caves open to the public in the United States. Development of industry standards.

25. Various microclimate, hydrologic, biologic, interpretive, and management investigations of caves in Missouri, .A.rkansas, Tennessee, Kentucky, New Mexico,

Arizona, California, Wyoming, Oregon, Alaska, British Columbia, New Zealand, and Australia.

26. Evaluation of 19 sites for designation as National Natural Landmarks; sites are in Indiana, Missouri, Arkansas, Iowa, Ohio, and New Mexico.

27. Assessment of hydrologic impacts of rock quarries. Multiple sites in Missouri, Arkansas, Maryland, Illinois, Alabama, and Alaska.

28. Assessment of the impacts of deep mining on regional hydrology. Missouri.

29. Preparation of sole-source aquifer designation petition. Missouri.

30. Delineation of wellhead protection zones for public ground water supplies in Arkansas, Missouri, Alabama, SoutJi Dakota, New Hampshire, Maryland, and Florida.

31. Feasibility study for creation of a national-scale American Cave and Karst Museum.

32. Instructor in numerous professional short-courses. These have included:

1) over 20 four-day courses in karst hydrogeology and groundwater monitoring sponsored by the Association of Ground Water Scientists and Engineers and by Environmental Education Enterprises;

2) two courses on groundwater site investigation techniques for health department professionals in Washington State; and

3) courses on land management in karst terrains for resource managers in West Virginia, Indiana, Kentucky, Tennessee, Missouri, Arkansas, Utah, Idaho, Oregon, Washington, Alaska, and New Mexico.

PUBLICATIONS

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5. 1964. Echinoliths--an important solution feature in the stream caves of Jamaica. *Cave Notes,* Vol. 6:1, pp. 3-5.

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A CONCEPTUAL CHARACTERIZATION OF THE SUBSURFACE MOVEMENT OF TOXIC CHEMICALS IN SOLUBLE ROCK LANDS

Tom Aley aod **Danny Halterman

In the past ·few years we have seen **a** dramatic increase in the number of soluble and fra tured rock groundwater problems which were associated with .:o:<ic chemicals. These have included chemicals such as polychlorinated biphenols (PBC's), 2,3,7,8-tetrachloradibenzo-p-dioxin (commonly called TCDD or dioxin), heavy metals (including chromium, copper, and ocher plating astes), and radioactive isotopes.

Soluble rock landscapes, and to some extent certain fractured rock landscapes, have some unique groundwater features not typical of other regions. As a result, the subsurface movement. of tolCic chemicals in soluble rock areas can be dramatically different fro what would be anticipated in a more hydrologically homogeneous envirorunent. It has been our ex- p rience th t these differences are seldom appreiated by tho management-oriented people who are **r 5pons1ble for· dealing w1c.n toxic cllt:w.Lcdo1 C"'ob ccs. As a result, thousands of dolla s have been** wasL d in poorly conceived study pro ra s, monitoring plans, and pollution control strategies.

n-.., f'U rpose of t:his paper is co provide c-he reader ••ith a general characterization and workable understanding of how toxic vasces move through the subsurface in soluble rock areas. To some extent, this charact:erization is also applicable co some fractured rock landscapes, and the reader should k ep this in mind even though fractured rock landscapes will receive no sp cific attention in this **paper. Furthennore, we urge that our ·conceptual** charac:cerization not be used in lieu of chemical-sp ci:ic and site-specific 1nvescigac1ons.

Ih.,erc ace three ·factois: of i:ricic.al im:,ortance in decer ining the sus eptibility of toxic chemicals **ca subsurface movement in soluble ro k lands. These** foctor;; **are:** l) the nature of the chemical, 2) the nature of the groundwater recharge system, and 3) **the nacure of the graundwacer sysc ro.**

"Consulting Ground ater Hydrologist and Director, lJzark Underground Laboratory, Protec., MO 65733

"'Consultant to the Ozack Underground Laboratory in biochemistry.

THE NATCRE OP 1'HE CHEMICAL

Toxic chemicals are commonly associated **wit.b** industri.11 anJ m11nicipal wast<.:S. Th.,.ic proper- **ties areas varied iIS cheir sources, aod uude r:-** St·anding che nature of these chemicals and d1eir interaccior.s is essential to pr<edictin_g their beha ior in groundwater systems.

There are rrc endous differences in the-water solubility of t.oxic chemicals. Toxic chemicals hich we have encountered can range: in water solubility from less than 2 parts per billion to co- tally soluble. People often tacitly assume that toxic. chemicals "ich low water solubilities wi.11 not Lause adverse impac.ts in groundwater sygtems because of the assumed dilution which occurs virh- in these syscems. In soluble cock landscapes, **th·l.::.. ..30.au.m.pt:i.on -iS1 cr..,rtnn... nly inv.:alid. At a minimum.** the assumptio<1 is less valid in soluble rock areas underlain by a more uniform porous media (suc.b as alluvi\JID or sandstone).

In cases involving toxic chemicals included in landfills, dumps, or industrial discharges, one must consider not only the solubllity of che **ehemical in water, buc also its solubility in** other liquids present at the site.. It sometimes occurs that a toxic chemical has a very low solubility Ln acer, but a high sol bility io cnrtain **solvents. Tf,e.se solv nts, in turn. can** havt: a high solubility in water.

There are also great differences in the adsorptive properties of coxic chemicals vich respect to soils. Chemicals with low adsorptive tendencies are likely to remain available for transport in solution through a groundwater system. Conversely, other toxic chemicals have high adsorption tendenci s and readily adher to soil and elay particles. If they encounter suitable soil particles with suitable and available adsorbing **surfaces, they can be rather rapidly removed from** waters moving through the subsurface.

Ihe ehernical stability 0£ toxic chemical• in groundwater syatems is also important. The stability of a compo nd may be influenced by a rang of condition found in the eu ircrJ:ienc. Aaaesa-m nt of stability based upon condition■ encolll\tered on the surface, hovever, do not necessarily reflect conditions eocountered 1n the ■ubaurfaca. 1n un-derground tcndi ion5 , for instance, ultTa-violet irradiation (frou the •un) ia absent; a1.1nlight irradiation of chloTinated hydrocarbon• can be an 1mpor ant destTuctive m chan1&c.

!he stable temperature of the subsurfac• environment is another condition enhancing stability of compound• chat would othen,ise deteriorate in the temperature excr meo of the surface.

B cc rial degradation of suma compo nds is yet an-ocher impoccanc destructive mechanism. Bacterial abundance decreases by ard rs of magnitude as on progresses deepeL into the ground. Bacteria are most abundant in the lesf litter and uppet111ost f• inches of the soil. It has been our experience that toxic chemicals tend to be significantly moTe stable in deeper ubsurface nvironcents than in surface and near-surface envlron ents.

Other p op rties and chaYacteriscics of toxic che-micals are also imporc&nt in assessing their pocen-t1a1 for subsurface igration and creation of harm-ful impacts in soluble cock areos. Kouever, mosc of these differences do no vary bet een soluble and insoluble rock areas. or bet een surface and subsurface conditions. Fo this teason we will not diccuss these prope.rtie.s .:md chac-.acteristics in chis paper.

NATURE OF THE CROUND ATER RECHARGE SYSTEM

In soluble rock landscapes, the movement of w3ter into che groundwater syste is typically non-unifor11. As a resulc. the subsurfa e: movement of toxic chemicals will also be non-unifoan.

Groundwater r charge is che movement of water from the surface to ard the groundwater s t m which underlies the land. tn oat soluble rock lands, it is our opinion th t roundwateT recharge can be divided into t""o classes; l) discrete recharge, and 2) dift se recharge. Tne distinctions betveen discrete and diffuse Techarge is discussed in de-tail by Aley (1977).

Discrete cecharge, which could also be called con-centrateU recharge, is the conc n rat d and rela-tively rapid movement of recharge Yater toward the sround"".a.teT system. Oescrete rech3rge is loc liz.ed; it occurs in discrete areas. Substantially greater quantitits of wateT per unit 2.rea enter the ground-w-ate.r sysc.etn throush di 's cr e t c recharge z.o:,es than through diffuse recharge.

Diffuse recharg refers to th general and rela-tively slo &eepage and pe colation of cecharge ater to a d the groundwater system. Dtffuse re-charge, by defini ion, is not conc ntrated flow.

Discrete recharse zcnes nave a much greater oten-tial for transporting r:cxic cher.i cal s in solution CoYard the groundwat r system chan do diffuse re-i.:harge a.re.as. Thi.? primary rea.son far this is chac discrete rec\Hl'C'ge zones pr,:;ivide less ef (eccive adsorr,t1.on t an do diffuse c- c.h.arge are.a.s. There arl! three eA7lanati ns ror chis dtffer-ence.

rhe firat explanation for the difference 1• that fiow rates ,hrough discrete recharge zoue• are typically much more raptd than chraugh diffuee recharse areas. As an exam;,le, surface ninfall 1n the Ozarkll recharging through diacrcte re-... charge conea causes major flow increa••• in near-by spring• within a f...., hours of the prac1pication: the d1ffuee flow component 1• delayed ao.d greatly attenuated (Aley, 1 77). The rapid tranoit ti..,s which characterize discrete recharge w ter• pTo-vtde lea• time for adsorption by soil particle• than ia the case with diffuae recharge tonu.

The second e:q,lanation is chat discrete recharge zones caDaDonly have been flushed of much of the fine te tured ma,erlals which could potentially adsor?> to>=.ic. chei:tica1s from C\Jnt.am1a..ac d vatet'; diffue recharge areas have not been flushed. It appears likely that \Jater_velocitice thrc,uch dio-crece rechArge iones occasionally are rapid enough and consist of enough water to vraseut turbulent flow conditions capable of cran o tir.g sub t n-tial quantilit!:5 of' cdimeat throur.h :1rd our of the discrete recha se zones.

The thitd explan.:ition is th '\t adsuq;t;.\,.,n of toxic chemicals by soils increases with i n,.- r r.;s1 1::; jn the amount iJf pocenti :11 .:Jds,,rbitti:, scr[ace з ri'.;,.,i e.ncountet"cd. Cont.iminzned '"''' i.:1" will, •11C1IJ IJt. • r a much smaller area of .;sot·binP., surfa::cs in <li.!.;-crete rech.irge i:on s (whic:11 arc CJftqlosed 11cia.irily of conduic.s) than in diff use rcchnr c areas (wh re intergr.1nular v.:icer movement prcdon:ir:.:H.< s). No data have been assembled ro uant.ify chc differ-ence 1n adsorbin-g urfacc ar as bctw cn distrc e and diffuse cccharg zones. but it ls Gur belief that the Ji f fere.nccs. could commonly be tt'.n to One hundred fold.

An mentioned earli r, d1scre e r ch.- rge ion<?S T capable of transporting materials in s sp nsiou; diffus recharge areas Te not. Bec usc of th s distinction. toxic chtmicals ad orbcd on clay par-ticles c n be tr;n ported c ruu h dLscrec r -charge zone. c.u the gr-ound'- :.r.ti&'t' system. This re-presents a suh "Jrfar.:c tTantport system vhich generally doe5 nee exist except ia soluble c =k landscapes In our experience, this tr nspo1c mechanism has seldoM eceived anyattention-

Clay particles, hich are typicaily s ll r than Cour mi- ror:s 1:-: i1i 3 me•t l:":r . i:r1n be tT.1 \ ported into and through groundwater systems in olubl rock areas. We believe that toxic chc.c,ical at!sorption on suspe d d clay par icles is commonly an impor-tant mec.hanis.m o! toY.ic chelllical tra,nsport in sclub1e Tock lands. *Lyaopodiwn* spores are a cc und·.,:i t e t' ::.racing agent ,.,,l1ich i:hc r.c r, io r outhor has used on a • n umbe r of occasions {Ale)· and Flt:c-cher , 1976). These sporl!s have a meaa diameter of 33 microns, thus they are substanttally larg r than th less than four micron dia.. eter clay par ticles onto which toxic chemicals can be adsorbed. Both spares and clay par i les ill travel tn su -c::nsi:n :cl,..'a d a:10 thro,:gh grui,'!"ld\.J'.1tP.:l" systems; if anyching, the clay particles 111 c nd t e-main in suspensior. for longer p rinds o! ime in calm aters chan will the S?ores.

'!'ht: st:!nior a1;th r t:.a:;; traced *LycopoC*,:ul:l .:ipcro:s from s nkhcles and sicking st ca s spr ogs as far as 39.5 miles distant from the injection aite. In add1t1on, spores have been successfully traced from a septic field to **a** domestic water supply well, and from tva wells which penetrated shallow caves to• major cave stream half a mile away.

Toxic chemicals with moderate to high water solubility and low to moderate adsorption tendency, will ost commonly receive the majority of their subsurface transport 1n solution. Toxic chem:1.cals with low water solubility and moderate to high adsorption tendency, will most commonly receive che majority of their subsurface transport in suspension if local subsurface conditions **are** conducive to sediment transport.

NATURE OF THE GROUNDWATER SYSTEM

Groundwater recharge contributes water to the groundwater system. It is the movement of water through the groundvacer system which is the topic for thls section of the paper.

A good conceptual model for dealing with groundwater in soluble rock areas should recognize that chere are cwo cooponencs of che groundw ter system. The terms "water in storage" and "wacer in t.ransic" have been used to characteri e these two components (,\ley, 1977).

Wacer in storage generally fits the conventional view of groundwater. Water in storage is characterized by slow lateral movement. In distinct contrast, water in transit is characterized by rapid lateral movement, co1111l\only at rates of from several Leet per hour co several hundred feet per hour. It would be illogical to label water moving at these rates through a groundwater sysce as water in storage. This rapidly moving vater is in transit, not storage. Obviously, the two classes (water in storage and waier in transit) are a c n-cinuum, for even the water in storage has some movl>ment. Rathar th,:rn hang ourselves w1th semantics, which is totally unnecessary for the purposes of this discussion, **we** P.ropose that flow races equal co or in excess of one foot per hour indi'cate water in transit, and rates less than one foat per hour represent w ter in storage.

Based on Nissouri studies (Aley, 1977), d1screce r charge zones tend to contribute most of their waters to water in transit, Diffuse recharge zo:ies conrribute water both to water in transit and vater in stora ge.

ln general, water in transic is underground far a shorter period of time than is water in storage In addition, contaminants introduced into water in transit tend tp cove as pulses through the groundwater system. In general, concarninants receive less dilution in waters in transit than they do in watecs in scorage. These distinctions between water in storage and water in transit are (vical imporcance 1n assessing the potential for subsurface 1!10vement of toxic chemicals.

\;i thi.n mosc soluble rock groundvater **systems** one does not generally encounter abundant 301\ parci les cap3ble of ad orptlon, although •cme exc ptlons to this 5eneralizacian undoubtedly occur. It there ls a dlffe:ence in contaminant expo ure to **adsorbing particles within soluble rock ground ater sy, tems, we anticipate tnat water in storage would be eXl)osed to moce adsorption** than would water in transit. ln **general, ma•t** adsorption vill occur above the groundwater syat= (in other words, w1.thin the grQuudwater recharge syatem).

If toxic chelllicals in solution reach the soluble rock groundwater system, we should expect th.ea to move widely through the groundwater **systea.** Toxic chemic.als entering through discrete recharge ones will contribute primarily to the vater **1n** transit component of the grouadvacer **ayscea; aosc** of the toxic chemicals introduced **w-111 discharge** ag pulses from springs draining **the area. Ta.d.c** chemicals in solution entering thrDugh **diffuse** ro,charg2 zones i,lll tyvi,ally li.,ve law to modcT-ate adsorption characteristics, and **vi.11 concri-**bute boch tD wacer in transit and to water in storage; they v.ill typically be detectable **iq** springs before they are detectable in wells, a1-though they will ulti ately be found both **io** springs and wells. Concentrations in Rpriogs .u,d welis vill be a function of the flow system; **ve** .cannot develop a gencrali ation as to whether con-centrations should be greater in springs or iu .wells since this is a sitc-speclfic **question.**

Toxic chemicals adsorbed on soil particles can reach the 6roundwatersystem through discrete recharge zones. Discrete recharge ones tend to contribute most of tbeir waters to the **water in** transit component of the groundwater system; *As* we have demonstrated through the use **of** *l,yccpodiUlfl* spores, water in transit can transport suspended materi ls. *As* a result, toxic cheadcals adsorbed on soil particles which eater the groundwater system should be.expected co discharge frOlll springs. They will settle and noc be traoSl)orted through the water in scorage system. Since wells nornally are extracting water in storage, to:d.c chemicals **ad-sorbed on soil** piirLi clcs ...,-;11 seldom be re.cove"t:ed from such Wt?.]ls.

We have characterized the likely movement of toxic chemicals in subsurface waters in soluble rock landscapes in an attempt co develop as many general conclusions about to 1c chemical movement in such landscapes os we could. Numerical verification for our conceptual characteri ation is generally lacking, yet the characterization fits our field xperience in cases involvin& subsurface movement of toxic chemicals in soluble rock **areas.**

We believe that our conceptual characterization will provide management oriented people with **a** better general characterization of subsurface toxic chemical movement in soluble rock **lands** than presently exists. Rowever, general characterizations can only provide general help in dealing with problems of subsurface movement of toxie chemicals in soluble rock lands. Our conceptual characterizations should not be used in lieu of chemical-specific and site-specific investigations We believe, ho•.-ever, that this conceptual characterization can be of substantial **value** in **gulding** the design cf 1nve9 t l a 10 p cc rd1J ; 1t hds b en our experience thac such guidance for soluble rack landscapes is urgently needed.

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Standard Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers [1]

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INTRODUCTION

This guide for the design of ground-waler monitoring systems in karst and fractured-rock aquifers promotes the design and implementation of accurate and reliable monitoring systems in 1hose settings where the hydrogeo1ogic characteristics depart significantly from the characteristics of porous media. Variances from government regulations that require on-site monitoring wells may often be necessary in karst or fractured-rock terranes (see 7.3) because such settings have hydrogcologic features that cannot be characterized by the porous-media appro:,;imation. This guide will promote the development of a conceptual hydrogeologic model that supports the need for the variances and aids the designer or governmental reviewer in establishing the most reliable and efficient monitoring system for such aquifers.

Many of the approaches contained in this guide may also have value in designing ground-water monitoring systems in heterogeneous and anisotropic unconsolidated and consolidated granular aquifers. The focus of this guide, however, is on unconfined karst systems where dissolution has increased secondary porosity and on other geologic settings where unconfined ground-water flow in fractures is a significant component of total ground-water now.

I. Scope

1.1 *Ju..stiflcalion*-This guide considers the characterization of karst and fractured-rock aquifers as an integral component of monitoring-system design. Hence, the development of a conceptual hydrogeologic model that identifies and defines the various components of the now system is recommended prior to the design and implementation of a monitoring system.

1.2 *Methodology and Applicability*-This guide is ba5ed on recognized methods of monitoring-system design and implementation for the purpose of collecting representative ground-water data. The design guidelines are applic:ible to the determination of ground-water flow· and contaminant transport from existing sites, assessment of proposed sites, and determination of wellhead or springhcad protection areas.

1.3 3 *Objectives-The* objectives of this guide arc to outline procedures for obtaining information on hydrogeologic characteristics and water-quality data representali\'e of karst and fractured-rock aquifers.. ·

1.4 *This standard does not purport ro address all of che safety concerns, if any, associa1ed 1i•uh its 11se. It 1s the responsihili1y of the user of 1/iis s/Qndard to establish appropriate safecy and healih practices and determine the applicability of regula1ory limiLations prior to rtse.*

2. Referenced Documents

2. I *ASTM Standards:*

D 653 Terminology Relating 10 Soil, Rock, and Contained Fl uids [2]

D 5092 Practice for Design and Installation of Ground Waler Monitoring Wells in Aquifersl

D 5254 Practice for Minimum Set cf Data Elements 10 Identify a Ground-Water Si1eJ

3. Terminology

3.1 Deflnilions:

3.1.1 For terms not defined below, see Terminology D 653.

3.2 Descriptions of Terms Specific To This Standard:

3.2. J *aliasing-the* phenomenon in which a hig.h- freque ncy signal can be interpreted as a low-frequency signal or trend because the sampling was too infrequent to characterize the signal.

3.2.2 conduit-pipe-like opening formed and enlarged by dissolution of bedrock and that has dimensions sufficient to sustain turbulent now under ordinary hydraulic grad ients .

3.2.3 *dissolution zone-a* zone where ex:ensive dissolution of bedrock has occurred; void size may range over several order.; .of illagnitude.

3.2.4 *epikarst a* zone of enhanced bedrock-dissolution immediately beneath 1he soil :wne; characterized by storage of water in dissolutionally enlarged fractures and bedding planes, and Lhat may be separated from 1he phreatic zone by

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t This ,uidc is undtr tht jurhdic1ion of ASTM Cum mince D- t 8 011 Soil :ind Rock and .s 1he dir«I mponsibili1y of Subcommiuc,: DIG.1 1 on Ground Woicr and V•do>e Zone lnves1ig:11ions.

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a relatively wau:rless interval locally breached by vertical vadose flow.

J.2.5 *fractured-rock aquifer-an* aquifer in which l1ow of water is primarily through fractures.joints. faults, or bedding planes that have not been significantly enlarged by dissolution.

3.2.6 *ka.rst aquifer-an* aquifer in which all or most now of water is through one or more of the following: joints, faults, bedding planes, pores, cavities, conduits, and caves, any or all of which have been significantly enlarged by dissolution of bedrock.

3.2.7 *karst terrane-a* landscape and its subsuiface characterized by flow through dissolutionally modified bedrock and characterized by a variable suite of surface landforms and subsurface features, not all of which may be present or obvious. These include: sinkholes, springs, caves, S"inking streams, dissolutionally enlarged joints or bedding planes, or both, and other dissolution features. Most karsts develop in limestone or dolomite, or both, but they may also develop in gypsum, salt. carbonate-cemented sandstones, and other soluble rocks.

3.2.8 *overflow spring-a* spring that discharges generally intermittently at a ground-water stage above base flow (compare with underflow spring).

3.2.9 *rapid* flow-ground-water flow with a velocity >0.001 m/s.

3.2. IO *secondary porosity-joints.* fissures, faults, that develop after the rock was originally lithified; these features have not been modified by dissolution.

3.2.11 *sinkhole-a* topographic depression formed as a result of karst-related processes such as dissolution of bedrock, collapse of **a cave** roof, or flushing or collapse, or both, of soil and other sediment into a subjacent void.

3.2.12 *slow* flow-ground-water flow with a velocity <0.001 m/s.

3.2.13 *swallet-the* hole into which a surface stream sinks.

3.2.14 *tertiary porosity-porosity* caused by dissolut1onal enlargement of secondary porosity.

3.2.15 *tracer-a* substance added to a medium, typically water, to give it a distinctive signature that makes the medium recognizable elsewhere.

3.2.16 *underflow spring-a* spring that is at or near the lowest discharge point of a ground-water basin and that usually flows perennially (compare with overilow spring).

4. Significance **and** Use

4.l *Users--"This* guide will be useful to the following groups of people:·

4.1.1 Designers of ground-water monitoring networks who may or may not have experience in karst or fractured-rock terranes;

4.1.2 The experienced ground-water professional who is familiar with the hydrology and geomorphology of karst terranes but has minimal famiiiarity with monitoring problems; and

4.1.3 Regulators *who* must evaluate existing or proposed monitoring for karst or fractured-rock aquifers.

4.2 *Reliable and Efficient Monitoring S_vs1ems-A* reliable and efficient monitoring system provides information relevant to one or more of the following subjects:

4.2.1 Geologic and hydrologic propenies of an aquifer:

4.2.2 Distribution of hydraulic head in time and space;

4.2.3 Ground-water fiow directions and rates;

4.2.4 Water quality with respect to relevant parameters; and

4.2.5 Migration direction, rate, and characteristics of a contaminant release.

4.3 Limi1a1ions:

4.3.1 This guide provides an overview of the methods used to characterize and monitor karst and fractured-rock aquifers. It does not address the details of these methods, field procedures, or interpretation of the data. Numerous references are included for that purpose and are considered an ,essential part of this guide. It is recommended that the user of this guide be familiar with the relevant material within this guide and the references cited. This guide doL not address the application of ground-water !low models in the design of monitoring systems in karst or fractured-rock aquifers. The use of flow and transport mode at fractured-rock sites summarized in Ref (1) [4] provide a mon: recent comparison of fracturent and transpon modeling.

4.3.2 The approaches to the design of ground-water monitoring systems suggested within this guide are the most appropriate metliods for karst and fractured-rock aquifers. These methods are commonly used and are widely accepted and proven. However, other approaches or methods of ground-water monitoring which are technically sound may be substituted if justified and documemed.

5. Special Characteristics of Karst and Fractured-Rock Aquifers

5.1 Karst and fractured-rock aquifers differ from granular aquifers in several ways; these differences are outlined in 5.2. Designing reliable and efficient monitoring systems requires the early development of a conceptual hydrogeologic model that adequately describes the flow and transmission charac1eristics of lhe site unde: investig;;iiun. Scc1ion S.J uu!line, various approaches to conceptualizing 1hese systems and 5.4 contains subjective guidelines for determining which conceptual approach is appropriate for various settings.

5.2 *Comparison of Granular, Fractured-Rock, and Kars/ Aquifers*-Table I lists aquifer characteristics and compares the qualitative differences between granular, fractured-rock, and karst aquifers.' This table represents points along a continuum. For this guide a karst aquifer is defined as an aquifer in which most flow of water is through one or more of the following: joints, faults, bedding planes, pores, cavities, conduits, and caves, any or all of which have been significamly enlarged by dissolution of bedrock (2). For this guide a fractured-rock aquifer is defined as an aquifer in which the flow is primarily through fractures that have not been significantly enlarged by dissolU1ion. fracture is "a general term for any break in rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints, and faults" (J). The following factors must b:: evaluated to properly characterize an aquifer's position in the continuum.

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TABLE , Compsnaon cf **Granular,** Frac:Jured•A.ock, 3rid **Karst Aquile (3)**

Aquiler Charac:1ens1ics	Acuder Type		
	Granular	Frac1ureo Roel<	Karst
Effective Porosity	MOSlly primary. 11v0ugh Intargranular porns	Mostly sec:onoary, wough Joints, trac1u,es. anc beoll1ng plane panlngs	Mosuy len1ary /secondary porosity modified by di$SC>luliof1); tl'lrougn **pores,** beOding platlBS, lractures. eor>llUils. and **c;aves**
Isotropy	**More** lsouopic	Prooably anisotropic	Highly ar,,si:,tropic
Homogeneity	**Mora** hOmogeneous	Less · homogeneous	Nori· homogeneous
Flow	Slow, laminar	Possibly repid and possibly lurnu1enl	Ukely rapid and likely lurbulenl
Flow Predictions	Carey's law uaJly applies	Darcy's law may not apply	Oart:y·s law rarely applies
Storage	Wdhin satural8d **a**	Within sallJJ'ated zone	Willlin tlOlh **saturate<! zone** and epikarst
Recharge	Oisperned	Primarily dispersed. **wiU, some** point reCJ'\arge	Ranges from aJmos1 completely diS()ef'Sed- 10 almost completely po,nt-reenarg e
Temporal Heaa Variation	Minimal variation	Moderrne variation	**Moderate** 10 **exU"eme \lana1ion**
Temporal Water Chemistry Variation	Minimal variation	Minimal 10 mederale variation	Mooerate 10 **extreme -vanation**

S.2.1 *PorosiLy*-The type of porosity is the most important difference between these three types of aquifers. ·All other differences in characteristics are a function of porosity. In a granular aquifer, effective porosity is primarily a consequence of depositional setting, diagenetic processes, texture, and mineral composition while in fractured-rock and karst aquifers, effective porosity is a secondary result of fractures, faults, and bedding planes. Secondary features modified by dissolution comprise teniary porosity.

S.2.2 lsoirop_v-Fractured-rock and karst aquifers are typically anisotropic in three dimensions: Hydraulic conductivity can frequently range over several orders of magnitude, depending upon the direction of measurement. Ground water in anisotropic media does no1 usually move pel'l)endicu!ar to the hydraulic gradient, but at some angle to it (4, 5).

5.2.3 *Homogeneily-The* variation of aquifer characteristics within the spatial limits of the aquifer *is* frequently large in fractured-rock and kar.;1 aquifers. Hydraulic conductivity differences of several orders of magnitude cnn occur over very shon horizontal and venical distances.

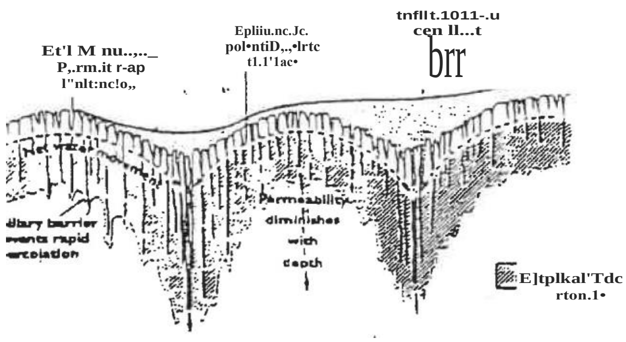
5.2.4 *Flow-Flow* in fractured rocks that are not significantly soluble is dependent upon the number of fractures per unit volume, their apertures. their distribution. and their degree of interconnection. Aquifers with a large number of well-connected and uniformly distributed fractures may approximate porous media. In these settings, the equations describing now in granular media. based on Darcy's law, are som::tim::s ;ipplicJble. f°r;:ic1ured-rock :iqu,i'er !ha[h:ive J iew localizeo htghly transmtssive frac:ures. 0r fr:icturc ;:ones that exen a dominam control on ground-water occurrence and move:nent. are not accurately c-haracterized by the porous-media approximation: they more closely resemble karst aquife:-s. Ground water moves through most karst aquifers predominantly through conduits formed by dissolution and fractures enlarged by dissolution that occupy a small percentage of the total rock mass. Ground-water flow in 1he rock mass is both intergranular and through fractures that have not been signiiicantly modified by dissolution. Such flow is usually only a small percentage of the volume of water discharging rrom the aquifer, thoug.h_ it provides most of the storage (6).

5.2.4.1 It was formerly thought, aft.er the work of Shuster and White (7), that conduit flow was dominant in some aquifers, and diffuse flow was dominant in mhers. The diffuse-now dominated regime was thought to be characterized by low variation in hardness, turbidity, and discharge-as measured at a spring. It is now recognized that the variations of these parameters are due to the aquifer boundary conditions, such as the number of sinking stream inputs or whether the spring is an under1low or overflow spring (8, 9, 10).

5.2.4.2 The terms *rapid flow* and *slow flow* should be used rather than *conduit flow* and *diffuse flow*. The latter terms are ambiguous when used in reference to karst aquifers because they have been used to describe types of flow within an aquifer, types of recharge, and types of spring-flow as affected by recharge events, as well as flow hydraulics, and water chemistry. Rapid flow takes place in conduits >5 to 10 mm in diameter (l l) where velocities generally exceed 0.00 I m/s. The swallet-tlow component ofkarn aquifers typically yields flow in conduits >0.001 m/s (10). Such rapid llow can also occur in open fractures. Flow in the rock matrix and through fractures that have not been significantly modified by dissolution is typically slow (<0.001 *mis).* However. flow in conduits and fractures can also be slow_

5.2.5 *Stor:age-In* most aquifers, ground water is stored within the zone of saturation (phreatic zone); however, karst aquifers can swre large volumes of ground water in a part of the unsaturated (vadose) zone known a£ the epikarst (subcutaneous zone) **(12,** 13, **14),** The epikarst, the uppermost portion of c<1rbona1e bedrock, commonly about IO to IS m thick, consists of highly-iractured and dissolved bedrock (see Fig. l). Highly permeable venic.il pathways are formed along intersections of isolated venical fractures. The epikarst behaves as a locally saturated, sometimes perennial, storage zone that functions similarly to a leaky capillary barrier or a perched aquifer. but it *is* commonly not perched on a lithologic discontinuity. Flow into this zone is more rapid than now out of it, as only limited vertical pathways trnnsmit water downward.

5.2.6 *Rechargi!-ln* granular aquifers. recharge tends to be a.really distributed and an aquifer's response to a given recharge event tends 10 be damped by movement of the recharging water through the unsaturated zone. Generally there is some temporal lag between a recharge even! and a resultant rise in water-table: water-table fluctuations in granular aquifers rarely range more than a few meters. By conm1.st, in karst and fractured-rock aquifers wi h minimal



FIG, 1 **CrQss•Section Il1us1ralin9 Epikarslic Zone** in **Carbonate Terrane (14)**

unlilhilied overburden, recharge lends 10 bc rapid: waler-levels may rise within minutes of the onsel of the storm and water-table fluctuations may range up to many tens of meters. Karst and fractured-rock aquifers with thick unlithilied overburden may have a long tempoTal lag similar to that of granular aquifeTS. RechaTge may be distributed through :m areully extensive network ol' fractures or through soil *(dispersed recharge)*, or it may be concentrated at points that connect directly to the aquifer *(point recharge).* The percentage of point recharge of ;:m aquifer strongly inOuences the character and variability or its discharge and water quality (10, **14).**

5.3 Conceptual Models of Gro11nd-Wa1er Flow in Frac-lUred-Rock and Karst Aquifers:

5.3.1 Three conceptual models of ground-water flow can be used to characterize fractured-rock and karst aquifers: continuum, discrete, and dual porosity. A hydrogeologic investigation must be conducted to determine which model applies **to** the **site** of interest.

5.3.2 The conlinuum model assumes that the aquirer approximates a porous medium at some working scale: (sometimes called the "equivalent porous-media" approach). In . this approach, the properties of individual fractures or conduits are not as important as the properties of large regions or large volumes of aquifer material. The porous-medium approximation implies that the classical equations of ground-water movement hold at !he problem scale, that knowledge of the hydraulic properties of individual fractures is not important, and that aquifer properties can be charac-terized by field and laboratory techniques developed for porous media. The discrete model assumes that the majority or the ground water moves through discrete fractures or conduits and that the hydn:iulic properties of the matrix portion of the aquifer are unimportant. Measurement of the hydraulic characteristics of individual fractures or conduits are used to characterize ground-water movement. The dual-porosity model or ground-water flow lies somewhere between that of the continuum and discrete models. A dual-porosity approach atlempts to characterize ground-water !low in individual conduits or rractures as well as in the matrix portion or the aquifer.

5.3.J These theoretical models are useful tools for concep-tualizing ground-water now in fractured-rock and kars! aquifers. However, lhe design of a ground-water monitoring system mus! be based on empirical data from the site to be monitored. ft is important to realize that standard hydrogeolog.ic field techniques may nOl be valid in fractured-rock and karst aquife . because many of these techniques are based on the continuum model. The following section provides subjective guidelines for determining whic.:h -:onccp-tual approach will best characterize ground-water llow in the aquifer under investigation.

S-4 *Subjec1ive Guidelines/or De1ermining the Apprupria1c• Cuncept11aJ Model:*

5.4. l The question of which conceptual approach is most suitable for a given aquifer is somewhat a question of scale. Implicit in the porous-medium approximation is the idea that aquifer properties, such as hydraulic conductivity. porosity, and storativity. can be measured for some represen-tative elementary volume (REV) nf aquifer material and that these values an: representative over ::i given ponion of the aqui/'er. For granular aquifers and some densely-fraclured aquifers. the REV is likely to be encompassed by standard field-monitoring devices such as monitoring wells. In such aquifers, the continuum approach is appropria1e for site-specific investigations provided aquifer heterog.em:ity is ade-quately characterized. The porous-medium approximation is not a valid conceptual model for !hose fractured-rock and karst aquifers where flow is primarily through widely-spaced discrete fractures or conduits. (14, l 5, **16).**

5.4.2 The discrete approach is most appropriate for those aquifers where there is a great contrast between matrix and fracture or conduit hydraulic conductivity. The dual-po-rosity approach is most appropriate for those aquifers where the matriK is relatively permeable and yet there are discrete 20nes of higher conductivity such as dissolution zones. fractures, or conduits.

5.4.3 Determining which conceptual model is appropriate for a given aquifer requires that an investigator determine the influence of fractures and conduits on the flow system. Existing data may provide valuable i nfo rmati on. However, relevant and appropriate site-specific field investigations are necessary to fully characterize the now system.

5.4.4 Below is a list of subjective criteria thal can be used to help determine which conceptual ground-water flow model is appropriate for use at a given site. Reference (3) lists several criteria for determining whether the continuum approach is appropriate for a fractured-rock aquifer; these are summarized in 5.4. l to 5.4.5. Additional criteria for determining the applicability of the porous-medium approx-imation in karst aquife (5.4.8) are provided by Ref **(2).** All of these guidelines **are** subjective because fract1ued-rock and k::irst aquifers range from porous-medium-equivalent to discrete fracture or conduit-dominated systems. The decision as to which conceptual model is most appropriate will always require professional judgment and experience.

5.4.5 *Ratio of Fracturr? Scale to Site* Scale-For porous-medium-equivalent aquifers, the observ·ed vertical and hori-zontal fractures should be numerous. the distance belween the fractures should be orders of magnitude smaller than the size of the site under investigation, and the fractures should show app recia ble interconnection.

5.4.6 *Hydraulic Cunduwv,1y Dwnbi111u11-l11* ;:;orous-rnedium-equivalcnt settings, the: distribution or hydraulic conductivity, as estimated from piezometer slug tests or from specific capacity analyses, tends to be appro:itimately log-normal. In aquifers where ,he hvdrau_\ic com.iurnvity distribution is strongly bimodal or polymodai. the porous-edium ::ipproximation is probably not valid. lt is also possible to obt::iin a log-norm:il distribu1ion of hydraulic conductivity for wells in those aquifers lh.ll do not lit the porous-medium approxima1ion (see 6.5) b cause most wells are preferentially completed in high- ielding zones. In addi- tion. hydraulic conductivity values vary with the scale of me:isurcment **(16, 17, 18,** 19) and slug tests completed in open boreholes will yield averaged hydraulic conductivities that do not represent the full variobility in hydrnulic conduc- tivity.

5.4.1 Waier-Table Configura1ion-For porous-medium-cquivalent aquifer.., a water-table map should show a smooth and continuous surface without areas of r::ipidly changing or anomalous water levels. In particular, the water table should not have the "stair-step" appearance that can occur in sparsely fractured rocks with large contrasts in hydraulic conductivitv between blocks and fractures, nor should the map exhibit contours that appear to ..V" upgradient, where no topogrJ.phic valley exists: In such settings, flow within a conduit may be affecting the configura1ion of the water table. Although the ..stair-step" or ··v-shaped" anomalies (for an example, see Ref (20) clearly indicate a failure of the porous-medium approximation, a smooth water table does not prove a porous-medium-equivalent setting because the density of measuring points may not be sufficient to detect irregularities in the water-table configuration {see 6.J. l.l).

548 *Pumping Tesl Responses-There* are several criteria for determining how closely a fractured-rock aquifer approximates a porous medium by using an aquifer pumping test.

5.4.8. I The drawdown in observation wells should increase linearly with increases in the discharge rate of the pumping well.

5.4.8.2 Time-drawdown curves for observation wells located in two or more different directions from the pumped well should be similar in shape and should not show sharp inflections, which could indicate hydraulic boundaries.

5.4.8.3 Distance-drawdown profiles that .are highly variable (for example, distant points respond more strongly while nearby points have little or no response) indicate that the porous-media approximation is not valid.

5.4.8.4 A plotted drawdown cone from a pumping test using multiple observation wells should be either circular or near-circular (elliptical). Linear, highly elongated. or very irregular cones, in areas where no obvious hydraulic boundaries are present, indicate that the assumption of a porous medium is invalid.

549 *Variations in Water Chemis1ry-Large* spatial and temporal variations in the chemistry of natural waters can be observed in fractured-rock and karst aquifers because of the rapid movement of water through discrete fractures or solution conduits. The coefficient of variation of specific conductance (or hardness) of spring and well water is a function of the percentage of rapid versus slow recharge to an aquifer and can be used to infer that percentage except where anthropogenic influences will impact the conductivity of the rechorging water **(8. 9, 10).**

5.4.9.l Many wells :md springs. panicularly those used for public woter supply, are sampled on a regular basis for such parameters as temperature. pH, specific conductance. hardness. \urbidity, and bactena. lf s.imp(ing results indic:ite large, 5hon-1erm lluctuations in anv of these parameter.:, the porous-medium approximation l.'..lnnm be assumed.

'.JOTC I-The l:ist sentence or the pr<e<0in paragraph as.sume.s 1ha1 1he shon-tcrm nuc1ua1ions I on 1he order or hours or d:iys°1 are no1 a consequence uf :n1aa1ion of pumping or 01h:r "-"tlhctrawal ,ne1hods.

5.4.9.l Water-supply wells J.nd springs are oiten sampled on :i. monthly basis and while monthly variation in wa1er-quality parJ.mete may provide a general indication of whether the aquifer behaves as a porous medium, water-quality variatio'ns in response to recharge events **are** frequently a better test of the porous-medium approximation. In order to determine the validity of the PO!Ous-medium approximation at a monitoring point, observe and record at least two, and preferably all. of the following: spring discharge or hydraulic head, turbidi_ty, specific conductance, and temperature. preferably a day before, during, and for several days or weeks after several major recharge events. If the water becomes turbid and the other parameters show rapid and flashy responses to the recharge event, the porous-medium approximation is most likely not valid. A bimodal ·or polymodal distribution of daily or continuous measurements ofspec:ific conductance **(14,** 21) also indicates that the ·porous-medium approximation may not be valid.

5.4. lO *Presence of Kars1 Fearures-The* presence in the same contiguous formation within several kilometres of a site of landforms such as sink.holes, sinking streams, blind valleys. and subsurface features such as caves and dissolutionally enlarged joints. indicaLes a degree of dissolutional modification tha1 probably invalidates the porous-medium approximation and denotes a kam terr.me. As a generalization. if there is carbonate rock, it *is* highly probable that there is borh a karst terrane and a karst aquifer. If a carbonate aquifer has been or is presently subaerially exposed, and if total hardness is less than 500 mg/L, then a rapid-flow component and a karst aquifer are present **(10).**

5.4.11 *Varia1ions in Hydraulic* Head-Monitoring wells in granular media tend to exhibit predictable and minor changes in hydraulic head in response 10 recharge events. In fractured-rocic and karst aquifers it is no1 uncommon to see large variations in head in immediate response to recharge events. The degree of response of hydraulic head in a given well is dependent upon the size of fractures or conduits encountered by the well and the directness oi ,heir connections to surface inputs.

5.4.11. I Aquifers with a high contrast in hydraulic conductivity over short disrances can exhibit non-coincident watc:r levels in closely spaced wells that are screened or open over the same venic::i! interval. l n K:.1rs1 :.ind fractured-rock terrane such non-coincident water levels indicate that the porous-medium approximation is probably not valid.

5.4. 12 *Borehole Logging-Severa!* borehole loggi rig techniques can help detennine 1f high-permeability z.ones are present within a borehole. The presence of such zones suggests that the aquifer is not a porou5-mc:dium equivalent. Zones of high permeability are indic::ited by the following:

5 'l.12. l Presence of open frJ.c1ures or dissolution features as indic:11ed by a caliper log, borehole television logs (for example. Ref (22)). or acoustic televiewer (23).

5.4. l *2.2* Significant variation 1n specific conduct::ince or temperature as interpreted from borehole logs (for e:r.ample, Ref (24)).

S.4.12.3 Signilic.int variations in borehole nuid movement as measured by a now meter in a pumped or unpumped well (for exa m ple, Refs (25, 26, 27, 18).

5.4. !2.4 Significant increase in porosity within a rock unit that otherwise has a constant porosity as measured by a porosity (neutron-neutron) log; and

5.4.12.5 Significant decrease in density within a rock unit that otherwise has a consistent density as measured in a density (gamma-gamma) log.

6 Hydrogeologic Setting

6.1 Hydrogcologic characterization of fractured-rock and karst aquifers is complicated by the presence of high-permeability fractures, conduits, and dissolution zones that **exert a** controlling innuence on ground-w.ater now systems. Locating and characterizing these high-permeability zones can be logistically difficult if not impossible, because conduits, dissolution zones, or subsurface fractures that lransmit a large percentage of the now may be as small as a few millimetres in size. Benson and Yuhr (29) note that borings alone are inadequale for subsurface characterization in karst settings. They provide some insights imo the number of borings required for locating a subsurface cavity by noting lhe detection proba biliti es. The example they provide is that "if a I acre site contains a spherical cavity with a projected surface area of 1/10 acre (a site to target ratio of 10), 10 borings spaced over a regular grid will be required to provide a detection probability of 90 %. Sixteen borings will be required to provide a detection probability of 100 %. . .for smaller targets. such as widely spaced fractures, the site- to-target ratio can increase significantly to !00 or IO00, thus requiring 100 to 1000 borings 10 achieve a 90 % detection confidence level" (29).

6.1.1 In granular media. the monitoring well is the standard measuring point for bcllh obtilining reprcscnlillivc ground-water samples and determining aquifer properties. However, the discrete and dual-porosity conceptual models require an investigator to identify sampling points and perform aquifer tests or tracer tests. or both. that do not rely on the porous-medium approximation (continuum approach). In karst and fractured-rock settings, an investigator cannol assume that a monitoring well will' provide representalive data either for waler-quality or aq u ifer charncleristics **(14,** 30, JI). Tracer tests (see 6.7) are one of the mon: valuable tools for determining ground-water flow directions and velocities because the interpretation of these tests does not require the porous-medium approximation (continuum app roach) .

6. 1 . 2 This section discusses the imponance of understanding stratigraphic and structural innuences on ground-water flow systems {see 6.2); location and characterization of frnc1ure pa!lerns and karst features (see 6.J): delineation of ground-water basin boundaries and now directions (see 6.4); applicability of geophysical techniques (see 6.5); and measurement of aquifer characteristics (see 6.6).

6.2 *Rn{iona/ Gc:nlogy and S1r11r11ire-* The design or :1 ground-waler moniwring network should 1nciudc a determ,. nation of how the site lits into the regional geologic setting because regional stratigraphic and structural patterns provide the: constraints within which the local ground-water now system is develo ped.

6.2.1 *Sources of* Dara-Information on regional geology and hydrogeology, (that is, geologic maps, stratigraphic cross-sections, geophysical logs from nearby sites, cave maps. water-table or potentiometric-surface maps, long-term records of waler levels or water quality in monitoring wells) can be obtained from both published and unpublished sources including federal and state publications, academic theses and dissertations, journal articles, and available consultants' repons. Additional information can be obtained from local land owners, quarry operators, highway departments. local construction lirms, as well as geologic logs, drillers' lo gs, and well-construction repons from domestic wells. Data on the number, distribu1ion, and cons1ruc110n o f domestic wdls are best obtained by housc -10-h o usc survey. state and federal files for most areas rarely include more than a small percentage of the wells thal exist. The most information about caves can be obtained from consultation with the National Speleological Society' whose: members compile information on a state-by state basis.

6.2.2 *In1egra1ing Geologic lnformarion With F/ow-Sys1em Characlerisrics-When* reviewing the existing data . an investigator should take extra note of any information that indicates the presence of conduits or high permeability dissolution or fracture zones (see guidelines outlined in 5. 4) . The initial hydrogeologic characterization should include a survey of bedrock outcrops in the area. Special attention should be paid to the relationships between stratigraphy and structure and the distribution of lineaments; fracture patterns, karst landforms, sinkhole alignments, and hydrologic features such as seeps or springs.

6.2 .J *St ra1i ,:raphy:*

6.2.).1 l n any layered rock sequence. either sedimentary rocks or layered volcanics, stratigraphy can be **a** controlling fac1or in !he development of zones of enhanced now of ground water. Bedrock CH11c ro ps. i ncl uJ 1 ng u11 1T1n :rn d caves. should be examined in order to determine lhe stratigraphic position of springs, **seeps.** caves, zones of dis solu tion , or zones of intense fracturing.

6.2.3.2 In fractured carbonate terranes, the development of conduits and dissolution zones is mos! commonly controlled by bedding plane partings rather than vertical fractures. Dissolution preferentially develops along bedding planes with substanrial depositional un conform iti es, planes with shale laminae or thicker panings, and planes with nodules or beds of chen **(14).** The relationship of shale beds or other low-permeability units to hydrologic features should he noted. These units cannot be assumed to provide effective barriers 10 ground-water 0ow because in fractured-rock and karst terrancs t hey **are** frequently breached by fractures or shafts (32). In carbonate terranes. interbedded shales are frequently calcareous and hence subject 10 d isso l u tion; in addition, shale beds may enhance dissolution, because of oxidation of included sulfides and production of sulfuric acid (9).

6.2. J.J In layered volcanic terranes. interbedded basalts ,rnd pvrot.:l.is1ic derosi1s b·,e L1, rTu cn1 h) J r0 lo 1c µ1opcrt1<'.$

' Na,iona l S DCl co log,cal Soc iety . Ca ve Ave.. Hu l\ls, ·ilk . AL J j 8 ! U.

Pyroclastic deposits c:in range grc:11ly rn 1:rms of primary porosity ,md hydrnulic conductivity due lo differences in welding and the development of secondary f rac tu res. In general. ash-flow Luffs in the upper pen.ions oi nows exhibit high values of porosity and permeability (33). ln nood basalts, the interf1ow zones (top of one now und bottom of overlying tlow) tend to be zones of high porosity and high conductivity due 10 primary depositional features such as --now breccias. clinkers, shrinkage cracks. now-top rubble. and ga.s vesicles" (33). In nood basalt tc:rranes, tubes or conduitS (lava caves) should be suspected. and although these features will usually be influential only in the shallow zone, they could cause preferential flow similar to a conduit system in a karst terrane. Springs are also common in volcanic rocks; their location is determined by topography, structure, and depth to ground water.

6.2.3.4 In regions wilh no quarries, accessible caves. and few bedrock outcrops, geologic characterization will have to be based on information obtained from drilling. Core drilling provides a good record of both subsurface stratigraphy and fracture distribution in areas of good core recovery. However, core recovery often fails in zones of poor rock quality or in areas with extensive voids. An alternative approach for such situations is to drill destructively (without coring) and then log the hoie with applicable geophysical techniques (that is, gamma, resistivity, or conductivity for stratigraphy, and caliper and television for fractures). While venical boreholes provide useful information about horizontal fractures and dissolution wnes. angle drilling with collection of oriented core can be used to better characterize vertical and near-vertical fracture systems, and steeply dipping beds (34). A review of existing well logs, including geophysical logs, should note suatigraphic zones where circulalion was Jost during drilling, where enhanced yields were: obtained during well development or aquifer tests, and where open or mud-filled cavities or fractures were encountered .

6.2.4 *S1ruc1Ure:*

6.2.4.1 Structural features commonly associated with concentration of ground-water flow include anticlines, synclines, and faults. Anticlines are imponant· because extension of joints along their crests can favor developrnenl of joint-controlled conduits. Synclin tend to concentrate flow, usually with down-dip inputS to a conduit located close to the base of the trough **(14).** Faulu, especially faults formed by extension, can concentrate ground-water flow, provided that they have not been filled by secondary mineralization **(14).** Faults can also provide barriers to ground-water flow if secondary ·mineralization or fault gouge is extensive or if a low-permeability fault block truncates an aquifer.

6.2.4.2 In dipping carbonate rocks (that is, 2 to 5° or more), initial ground-water flow is commonly downdip with eventual discharge along the strike of the beds. ln these settings there is substantial evidence that strike-aligned flow is common, and can extend up 10 tens of kilometres . When designing monitoring systems in these settings. discharge points along the strike must be located even if they are several kilometres away from the site to be moni1ored. In dipping carbonate strata, depth of ground-waier circulation is influenced by fissure frequency, down-ciip resistance to tlow, ground-water basin length. :ind angle oi dip (9. 14).

6.2.4.J ln crystalline rocks. fractures are typically most abund:int near the land surface: fracture densitv diminishes with deplh . However, high-permeability Cractur s have been found at depths greater than 1500 m (35). Water-table configuration and hence ground-water new direction in these se1tings appears to be 1opogr.iphic::illy controlled (36). Enhanced well-yields indicate that the z.ones of enhanced ground-water flow occur along fracture traces. at the inter• section of fracture traces and in valley bottoms which are probably fracture-controlled (36, 37). Reference (37) also notes that "sheet joints", subparallel 10 the land surface at shallow depths and horizontal at greater depths, may play an imponant role in ground-water movement in plutonic rocks.

6.3 *Field Mapping and Si1e Reconnaissance-In* areas where the surficial materials are thin or absent. high-angle fractures and the location of large karst **features** can sometimes be mapped from topographic maps and aerial photographs. Most fractures and many karst features are not recognizable on topographic maps or air photos and field mapping will be necessary to locate \hem. Fieid reconnaissance, completed early in the project, is an 1mponant component of site investigation and is essential for the: identification of open fractures, swallets. small sinkholes. springs, and cave entrances. (A detailed discussion of fracture-mapping methods can be found in Ref (38). Fractures and karst features will have a large impact on the subsurface hydrology, ven if their surface expression is slight. Field mapping can provide detail on the distribution of karst features and on fracture orientation and density. However, it gives little information about the distribution of fractures or conduits at depth.

6.4 *Determinacion of Ground-water Flow Directions. Velocilies. and Basin Boundaries-Water-table* or potentiometric-surface maps, or both, are used 10 estimate the direction and rate of ground-water and contaminant movement in l}Tanular aquifers. Such estimates are complicated in fractured-rock and karst aquifers. Even porous-medium-equivaleni fractured-rock aquiiers frequently exhibit significant horizontal anisotropy, which can make prediction of ground-water flow directions difficult. Some fractured-rock aquifers respond rapidly enough to rccharg evrnts :hat temporary ground-wa1er mounding may develop and lead to reversals of flow directions. The concept of a •'water-table:" becomes less clearly defined in those fractured-rock and karst systems where there are discrete high-permeability zones in a much lower-permeability matrix. In these settings, the fractures and conduits respond quickly IO recharge events and may spill over into empty, higher-lying conduits or fractures while the lower-pemieabiiity ponion of the aquifer remains unsaturated.

6..5 *Variation of Hydraulic Head:*

6..5.1. *Potenciometric-Surface* Mapping-Constructing a potentiometric-surfacc: map with water levels from existing wells assumes the following: venical hydraulic gradients are *not* significant. arid the well intersects ::nough fractures or conduitS to provide a representative water level for the aquifer. If significant venical gradients are present. construction of a potcntiometric-surfacc map will require screening out of apparent · anomalies in water levels resulting by measuring water levels from wells cased at different depths in an aquifer's recharge and discharge 20nes (39). The elevation or base-level springs. lakt'.s. and sirc::;ims should be r:g;ardtd as possible data poi n ts for :i potenliometric ma p, prov ided i t can be established that they are not perched .

6.5. l . l When constructing ;1 po te ntio metric map based on fiel d-measured . wai::r levels. it is necessary to measure water levels in all r'eprese nta1 i ve accessible wells over a short time-interval. Data from existing wells may be adeq uate , provided well-construction i n form atio n is available, and the water-levels are evaluated with respect to the length and depth of the open interval. Depending on the nature of the investigation and the level of detail req u i red, it may be neces.sary to install additional wells .

6.5 . 1 . 2 It is difficult lo stale a universal rule that unambiguously specifies the appropriate contour interval or the density and distribution of data points that are needed for construction of a pou:ntiometric map. The steepness of the hydraulic gradient guides the choice of contour interval and \he dala density should be such that, on average, no more than two to three contour lines are in te rp ola ted between data points.

6.5.1.3 Contaminants in karst terranes can quickly travel several kilometres or more. Therefore, it is necessary to extend potentiometric maps significantly beyond property boundaries in **order** to determine the likely extent and direction of contaminant travel, and to increase the accuracy of the map .

6.5.2 *Vertical Distribution of Hydraulic Head:*

6.5.2 . 1 The: vertical component of OO\v should be considered in the delineation of ground-water flow di rection . Groundwater flow systems typically have a downward flow component in recharge areas that gradually becomes hori- zontal before changing lo upward flow in discharge areas. In granular and porous-media equivalent aquifers, vertically nested or closely spaced pieiomc:ters along the now path arc sufficient to describe these gradients.

6.5.2.2 In karst aqu ifers, the matrix, frac tu res, and conduits each have very different vertical flow regimes which can be difficult to characterize. For some karst aquifers, recharge: is concentrated at very specific poinLS (for example, at sinkholes and swallets of sinking streams) that feed a complex network of conduits. Whether flow is predominantly horizontal or vertical at various points along the now path is controlled by hydraulic head, the geometry of the conduit system, and location of the discharge point. The **degree** of connection between the fractured and matrix portions of the **aquifer** and the conduits will be a function of fracture density, primary porosity, extent of dissolution, and hydraulic gradient. Characterization of the vertical component of flow in conduit-dominated aquifers requires locating point inputs and poinl discharges, determining the vertical component of now in the fractured and matrix portions of the aquifer, and evaluating the degree of connection between the fractured and matrix portions of the aquifer and the conduits.

6.5.3 Temporal Changes in Hydraulic Head:

6.5.3. J The response of springs or wells to recharge events is useful for characterizing an aq uifer . On lhe continuum from porous-media-equivalent aquifers lo discrete fracture or conduit-dominated aquifers, head variations in the latter lend to increase in magnitud e; Jag times lo the hydrogra ph peak afler the recharge event tend to decrease. In brief. flow in aq!Jifers with numerous direct sur face inputs (point rechar ge) and discrete fractu res or cond uits 1s more flashy than i n t hos e aquifers where di rect surface inputs are mi n i ma l. l ndiv idua l well-responses to recha rg e ev en ts can be used to indicate the degree of connection b tween the well and t he fracture or conduil syst em .

6.5. J.2 Complex responses 10 recharge events commonly occur in fractured -roc k and karst aq uifers . Flow-system configurations can change dramatically *in* response to recharge events. In karst aquifers, as deeper conduits fi ll . ground water may spill over to higher conduits and discharge to a different ground-water basin than it does during low-flow conditions (30, **40).** Moderately penneable frac- tured-rock aquifers may also exhibit such ground -water flow reversa ls if temporary grou nd-wa te r mounds devel op (40).

6.5.3.3 lnvestigalors working in fractun:d-rock and karst aquifers need to assess whether temporal changes in hydraulic head can lead to changes in ground-water flow direction or the positio n of ground-water basin boundari es. The frequency of water-level measurements needs to be determined by the variability of the system rather than by reporting requirements. Continuous waler-level records on representative wells are recommended in the early phase of the i nvest igatio n; after mon i toring the response of an aq uifer to several recharge events, the measuring frequency can then be adjusted.

6.6 Determination of the Directions and Rares of Gro1md-l·Va1er Flow:

6.6.1 *Flow* Directions-Water-table and potentiometric• surface maps arc valuable guides for predicting ground-water flow directions. However, the predicted flow directions will be correct only if the assumption of two-dimensional Oow is valid and anisotropic aquifer characteristics, if present, are laken into account. In some fractured-rock aquifers and most karst aquifers, the assumption of two-dimensional flow is proba bly not valid and anisotropy ratios are frequently unavailable for site-specific scales **(15, 18).** In somi: seuings the potentiornetric surface can provide a reasonable first approximation for the delineation of ground-water !low directions and basin boundaries, but this approximation must be confirmed with tests that are not dependent on the assumption of two-dimensional now. Such confirmation can be provided by properly conduc1ed tracer tests performed on both sides of a proposed boundary, as shown by Quinlan and Ewers (40) and discussed by Quinlan (30, 3I) .

6.6.2 2 *Flow Rates-It* is usually inappropriate to use water-table or potentiometric surface-maps lo predict re- gional or local ground.water flow rates in fractured-rock and karst aq uife rs. Such calculations assume ,hat the porous- media approximation is valid, now is two-dimensional, and the hydraulic conductivity distribution is relatively homa ge. neou s. While these conditions might be met over very shon distances, they are ra re l y, if ever, mel for site-specific ot larger areas. See 6.9 for a discussion of aquifer characteris- tics. Flow rates arc directly detennined from the results of aqu ifer-sca le or site-scale tracer tests.

6.7 U se of Tracer Tests:

6.7. I Tracer tests are a valuable too l for ch ra c1enzau on of fractured- rock and karst aq uif ers. They can yield em pir - ical d et erm in at ions of ground-water now directions. now rates , flow destinations. and basin bou nda ries . The results of these tests depend on the conservative nature of the tracer, i!S unambiguous detectability, proper test flesign and execution. .ind correct interpretation.

6.7.2 Two broad classes of tr.icer.; have been used: labels and pulses. both of which can be usefully subdivided imo natural and artificial tracers. The purpose of the labels is to enable identific.ition of the investigator's water which serves as a surrogate for a pollutant. The purpose of pulse-tracing is to be able to send an identifiable signal through the ground-water system. A partial outline of tracers that has been used can be found in Table 2.

6.7.3 The various types of tracers have different advantages .and disadvantages and they yield different types of infonnation about a hydrogeoiogic system. As the level of sophistication of an investigation increases, comparison of the results obtained with different tracers can often yield additional information about the system properties.

6.7.4 An ideal tracer has the following properties. It is:

6.7.4.1 Non-toxic to people and the ecosystem;

6.7.4.2 Either not naturally present in the system or present at very low, near-<:onstant levels;

6.7.4.3 In the case of chemical substances, soluble in water with the res·uJting solution having appro imately the same density *as* water; (care should be taken, in the design of tracer tests, to address concerns that may arise when the pollutants of concern are light or dense non-aqueous phase liquids);

6.7.4.4 Neutral in buoyancy and. in the case of particulate tracers, with a sufficiently smaJl diameter to avoid significant loss by natural filtration;

6.7.4.5 Unambiguously detectable in very small concentrations:

6.7.4.6 Resistant to adsorptive loss or to chemical, physical, or biological degradation, or all of the aforementioned;

6.7.4.7 Capable of being analyzed quickly, economically, and quantitatively;

TABLE 2 Typc,s of Tr.,cer5 (43)

!.Boers:
Natural
Flora as,c launa (Chiefly. bu1 no! e>elus;ve,y m1c100rganisms)
Ions in solut;on
Environmental isotopes
Tempara11.1re
Specific conai.ctance
Introduce<!
Dyes and dye-intermeoiates
Raaiomemc;aJly delect1,<1 suDstance•
Sans ano 01ner inorganic compcunos
Spores
Fluorocat00ns
Gases
A wide variety of org!ll'l;c compounas
Biological enlilias (bacten:a, viruses . yeasts . phages)
Etfluent and spilled substances
Organic **panicJas .** rrncrosphares
inorganic pai,icles (induaing sediment)
Temperature
SpecWc conductance
Exo1ica (eels, duCJ<s. mali<ed fish, ecc.J
Pvlses Sigmlicanlly Abov• Background or 8s:s6·Flow Levels:
Na1ura1
Disc.'large (cllange in siage or llow)
Temperature
Turtlidity
1n1roouceo
Oiset\arge
Temperalure

6.i'.4.3 Easy 10 introduce 10 the now system: anc

6 .i .4.9 Inexpensive :ind readily available.

6.7.5 Non-toi\icity is the most imponan1 tracer char:meris tic . few tracers satisfy all of these criteria. but several of the tluorescent dyes meet most in many situations. For most settings. dyes are the most pr:ictic:il tracers. Tox1c1ty studies indicate that most fluorescent dyes are not harmful in the concentrations conventionally employed in tracer tes ts. l1 has been determined that a concemra,ion of one part per million of the most commonly used fluorescent dyes. over an exposure period of 24 h. poses no threat to human or ecosystem health **(41).**

6. 7.6 Tracer tests an: appropriate when:

6.7.6. I Flow velocities are likeiy to be such that results will be obtained within a reasonable period of"time. usually less than a year;

6.7.6.2 The consequences of existing or possible future ground-water contamination must be determined:

6.7.6.J It is necessary to delineate reL· harge atea.s or ground-water basin boundaries; or

6.7.6 .4 It is necessary to design or test a ground-water monitoring system, or both.

6.7.7 Tracer tests can be classified in several ways which are outlined in .Table 3. Techniques for trac:ing ground water, with emphasis on the use of fluorescent dyes, are described and discussed in Ref (43).

6.7.8 Tracing techniques and approaches that an investigator might use vary greatly in levels of sophistication. For example, the question "ls the septic system of this house connected to the nearest sewer main?'" can sometimes be adequately answered with a few pennies wonh of dye and a few minutes of someone's time. Similarly, questions about the internal connections in some caves can often be an- swered with about the same level of resources and time. ln contrast, questions about the regional-scale dispersal of pollutants from a major Superfund site in a densely popu- lated karst terrane require a considerably gre:ner investment of time, resources, and effon.

6.7.9 9 Dye-detection techniques range from visual detec- tion, to detection by tluorometer, to instrumental analys1 uf water samples using a scanning spcctrof1uorophotometer or (rarely) high performance liquid chromatography (HPLC).

TABLE 3 Classilieations of Tracer iests (43)

A. *Degrae of Quan1iliea 1ion:*
Qualitative
Semi-quan0lali•e
Quantitative
B. *D99r•s of Aheration* or *Hyorau/ie* GraCllenr:
Natural 9rad;en1
Forced gradient. accompl;snea by:
injec!ioo f1npu1 ra,ses ooten11ome1nc surtacel
Oisel>arg, fpump,ng lowers PolenIiomeInc suriace)
C. *Typs* of *ln111Crion* Sile:
Natural
Sinknole' or swallet
Cave ,roam
Anilicilll
From a **weR** or 01her man-made <:.'.lntnvanc.e
D. *Type at* *Aecovory* Sire:
Natural dischar9e sile
Sonng. cave stream. elc.
Art,hoaJ Oi SCI\Bl ge site
Mon1tonng well
One *or* more domestic wells

The use of simple visual detection of dyes is now considered usuaily unaccep1able in a major project. bul ii can s1ill be a very effective demonstration of ;i connection in some et-tings. ..

6.8 Gl!ophysical Techniqlu: s:

6.8.1 Geophysical lechniques c:an be used in a number of ways lo aid subsurface investigations and 10 characLcri2e some subsurface features of karst or fractured-rock aquifers (29, **44).** Surface geophysics can provide general information over a large area and can also be used 10 provide detailed. site-specific data . Borehole logging techniques provide localized information wilhin and immediately .iround a borehole or well. Some borehole or hole-to-hole techniques can be used to detect fractures and karst features. The method or methods to. be used must be selected 10 meet both project objectives and site conditions. Interpretations based upon surface and borehole geophysical data should be verified by other data and require experienced lield crew and interpreta-1ion.

6.8.2 *Surface Geophysical Techniq,ies-Surface* geophysics provides a means of characterizing subsurface conditions by making measurements of some physical parameter (acoustical properties, eleclrical properties, etc.) at the surface. Surface geophysical methods can help characterize subsurface features such as depth to rock. depth lo water !able. or to locale buried channels. **Large** structural features such as dip, folds, and faults can be located and mapped. Fracture orientation and areal variations in water quality can also be detennined. Surface geophysical methods can sometimes be used to detect conduiLs directly if they are shallow and large enough (29, 44). Effective-ness of surface geophysical methods diminishes as the feature or interest occurs at an increasing depth and with decreasing size or the feature. Fractures or conduits that are deeper than can be detected by surface geophysical methods. can some• limes be located indirectly by using near.surface indicators (29, **45}.** Geophysical methods are often used to indicate anomalous conditions caused bv a fracture **or** conduit. The anomalous conditions can t hen be investigated further by boreholes where the borings are focused into the anomalous area(s) and have a much better probability of encountering the fracture or conduit than a randomly placed boreho le.

6.8.2.I Surface geophysics may be a good reconnaissance tool that can be used to determine areas in need of further study. Several of the following methods may be applicable in fractured-rock and karst settings, including ground-penetrating radar, electromagnetic or electrical resistivity surveys, natural potential (SP), and or microgravity. Such mt:thods as electromagnetics **(46, 47, 48)** azimuthal resistivity **(48,** 49), and azimuthal seismic measurements (50) can be applied lo determine dominant fracture orientations.

6.8.3 *Borehole Logging Methods-Borehole* logging canbe used to identify strata (for example, shale versus limestone) and to correlate stra1igraphy between boreholes. These methods arc particularly useful for investigation of fractured-rock aquifers because they provide detailed information about rock properties in the immediate vicinity of borehole walls. They are useful for determining water-bearing zones within a borehole and for determining hydraulic properties of inclined and horizontal fractures (see Ref (51) for general borehole logging techniques applied to ground water investi• gat io ns).

6.8..3.1 Borehole logs most commonly used 10 correlate: stratigraphy include natural gamma, gamma-gamma, resistivity (or conductivity), and spon1aneous potential. Borehole methods panicularly useful for locating :ind charac:erizmg fractures and conduits include video. temperature, caliper, ncoustic leleviewer, now meter. borehole fluid logging, and cross-hole tomography **(29,** 44). When budget limitations preclude the use of multiple logging techniques, it is recommended that video logging be used to determine the location and orientation of fractures and conduits to aid in **the** placement of monitoring well screen. Tomography carried out by radar and attenuation of higher frequenc:y acoustic signals can be used 10 detect fractures and conduits.

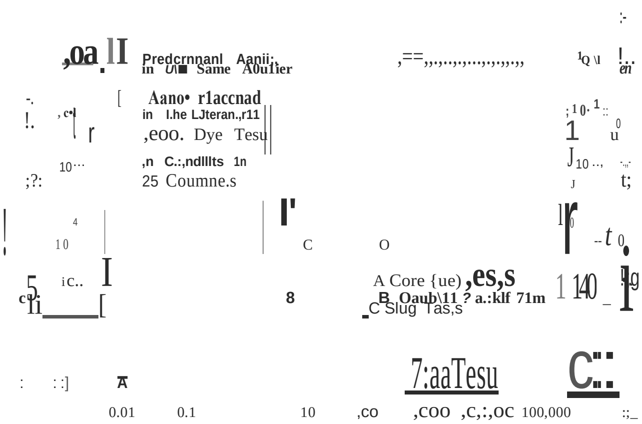
6.8.3.2 Borehole methods are often used in con;unction with each other. Borehole diameter, well construction. and proper well development can a!Tect the results and usefulness of borehole logs.

6.9 *Aquifer Characieriscics-One* of **the** special problems of monitoring in fractured-rock or karst aquifers **is that** aquifer characteristics such as aquifer thickness, porosity, hydraulic conductivity, and storativity can be difficult to q uantify .

6.9.l Aquifer Thickness-In aquifers with mainly primary porosity, the 1hickness of the aquifer can frequently be defined by litholog.ic or stratigraphic boundaries. In tracturcd-rock aquifers. fracture density and apenure frequently decrease with depth and it is difficult to detennine at what depth the fractures are no longer capable of transmitting significant amounts of waler. faamination or cores and borehole logging data may be helpful in ide·nt if ying the .. productive" portion of the aq uifer . Karst aquifers present similar problems in that karstification may decrease with depth or be confined to very specific zones or beds within the carbonate rock. While it is often difficult 10 determine the base or karstilication, Wonhington (9) suggests lhat stratal dip and length of ground-water basin can be used to estimate the mean depth of flow . Reference (52) suggests that packer tests at successively lower depths can be used for estimates of depth of karstification.

6.9.2 *Porosiry-Primary* porosity can be measured on the scale of a hand sample or **a** core sample; secondary and tertiary porosity need to be measured at a scale that statistically represents the distribution of heterogeneities in the aquifer. For densely-fractured rock, the sample volume may be relatively small and encompassed by borehole geophysical measurement techniques, while for aquifers with widely spaced heterogenc:ities (tha1 is. sparselv fractured roc k or conduit systems) the huge volume of ro·ck needed prohibits meaningful evaluations of porosity.

6.9.3 *H ydra11Ji c Cond11ctivicy and* S1ora1iv/1y-Hydraulic conductivity values vary with the scale of measurement **(16,** I 7, 53). The range of hydraulic conductivities and associated ground-water velot:ities for karst aquirers is illustrated in Fig. 2. Hydraulic conductivity values from lab Jnd field tests (Methods A through D) are compared to velocities of ground-water now in conduits (Method E). The presence of conduits in a karst aquifer requires a dual-porosity approach to aquifer characterization, or at least a discrete-porosity approach, rather than a porous-medium approx.imacion because the hydraulic conductivity would be grossly under- estimated with the porous-medium approach.



Nore-The Clala represented by neavy bars are from a Jur1ss1c 1<ar.;1 aquifer in Iha Swabian Alb or Garmany, as oascnbed by Sau1er (ti9) . The hatchured bo,c rapnisencs velocity data lrom more than 1800 dye traces trom !,inking W&Btns to springs (ll'lat ls, in condUits) trom 25 countrilts (modifi!K1 attar 116, 69)).

AG, 2 **Range** in Hydraulic Conductivity and Ground-Water Velocity in **Kant Aquilera as a** Function of Scale ol Measurement

6.9.J. l Hydraulic conductivity in granular media is frequently evaluated by single-well or multiple-well pumping tests. Results of such tests pe:formed in fraC'!ured-rock. and karst aquifers should be imerpreted with respect to the ponion of the aquifer that responds and the measurement-**scale** effects, illustrated in Fig. 2 should be recognized. The **discrete** nature of high-conductivity zones in fractured-rock and karst aquifers can yield hydraulic conductivity values ranging over several orders of magnitude at a specific measurement scale. Figure 3 illustrates the range of hydraulic conductivity values measured from slug testS (borehole-scale) at a smaJI site in horizontally-bedded fractured dolomite. Significant errors can occur when aquifer characterization tests are designed. conducted , or inte111reted without regard to the portion of the aquifer being tested.

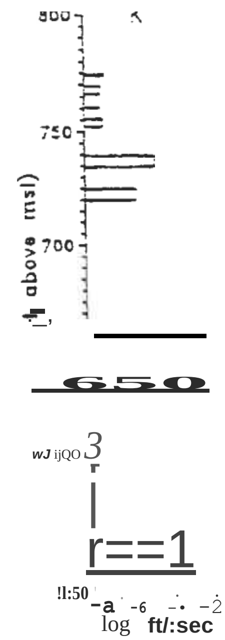
6.9.J.2 Site-specific investigations may require detailed information on the transmissivity of specific zones within the aquiier. In fractured-rock and karst aquifers. borehole **packers** can be used to **segregate** specific zones within the borehole. Slug tests and single-well pumping tests can then be performed to detennine transmission characteristics of different ponions of the aquifer. Borehole-fluid logging in **a** pumping well **(24)** c:i.n also help to characterize the producing zones within fractured-rock aquifers.

6.9.3.3 Measurements of transmissivitv and storativitv averaged over **a** ground,water basin in kar t aquifer-s can b estimated from discharge rates at springs (32, 52). Such averaged parameters may be appropriate for regional assessments of ground-water resources but they are less appropriate for site-specific investigations.

7. DeYeloping a Reliable Monitoring System

7.1 *Applicable Moniionng Points:*

7. 1. 1 Detennination of applic::ible monitoring points will depend on which conceptual approach masc accurately describes the setting under investigation. If the aquifer deviates significantly from the porous-medium approxima•



Non-Ele•ation Is 011 the •ank:al axis llanC: surface is 800 n (243.84 m) a00ve m.i J. 1nici<nu5 01 bar indicates lenglh ol **open** in1erval. 1eng1h or the ba,r nd ica1es measureo hyaraulic conductivlly . Hydraulic conductivuy values **range** *ov..-* five orciars ol magnI1uoe (complied from oa1a in Ref 1171):

FIG. 3 Range o! Hydraulic Conductivity Values from Slug Tests (Borehole-Scale) at a Site in Fractured Dolomite

tion, monitoring wells probably will not yield representative ground-water samples unless it is demonstrated by properly designed tracer studies and hydraulic tests that the moni•toring points are connected to the site to be mo nitored. Alternative monitoring points (such as springs, cave streams, and seeps) are usually more appropriate in kan.t terranes. These natural discharge points intercept t1ow from a larger area than a monitoring well and , as a result, they are more likely 10 capture drainage from a site. Monitoring sites that integrate drainage from a large :i.rea are likely ro show more dilute concentrations of contaminants than monitoring sites that intercept drainage from a small area . Monitoring of alternative sampling points requires evaluation of the significance of dilution of contaminants. Designe of a monitoring system must weigh the desirability of analysis of diluted waters that are known to drain from a site versus analysis of waters that are not demonstrably derived from the site.

7.1.2 Current ground-water monitoring practices utilize both upgradienc and downgradient-monitoring points in order to meet regulatory requirements. In fractured-rock and karst aquifers. rapid variations in hydraulic head can lead to changes and evtn reversals in ground-water now directions (see 6.5). In these settings, de1ermination of flow-directions from water-table or pocentiometric maps may not be adequate 10 determine placement of monitoring points. Samples for background water-quality should be collected at springs, cave streams. and wells that yield water that is geochemically represen tati·ve of the aquifer. These monitoring points might be located in an adjacent ground-water basin (30, 31". **54).**

7.2 *Methods of Testing Applicability of Monitoring*

Poims-Tracing studies and hydraulic tests should be used to demonstrale whether or not sampling sites arc: connected to the site bc:ing monitored. "'Downgradient'" monitoring-points cannot be assumed to intercept drainage from a site unless a positive connection from the site 10 the monitoring point is demonstrated.

7.2. I *Tracer Tesis:*

7.2.!. I Tracer tests that monitor the presence or absence of tracer at monitoring points are usually sufficient for determining now directions and validating monitoring points. Tracer tests in which tracer concentration is determined on samples collected at short-time intervals (that is, minutes to hours) can be used to determine optimum monitoring frequency that avoids aliasing; without !his knowledge a large number of monitoring points might be sampled for contaminants more frequently or less frequently than is necessary for accurate characterization.

7.2.1.2 Measuring tracer concentrations and discharges at monitoring points can provide additional mass-balance data that will make the design or modification of a monitoring system more efficient. At sites where there are multiple flow-directions and discharges to numerous monitoring points, it is useful to know whether a majority of the site's drainage is lo one or just a few of the monitoring points, as contrasted with nearly equal discharge to all of them. This mass-balance data can also be used to assess the significance of contaminant dil u ti on.

7.2.1.3 As a general principle, the cost-benefit ratio of measuring both tracer concentration and discharge rises as the number of potential monitoring points increases. If mass-balance tracing results are deemed necessary, qualita- tive traces should be performed first. This may eliminate the cost **of** sampling and analyzing monitoring points which do not receive tracers. For a discussion of mnss-balance tracing techniques as applied to the design of ground-water moni-· taring plans, see Refs {30, 43, 55, 56).

7.2.1.4 The mass-balance tracing technique described *by* Mull et al. (55), would be useful (in some settings) for evaluating the possible consequences of a spill into an open sinkhole draining to a cave stream. However, this technique is incapable of evaluating !eakage from a waste disposal site. Therefore, use of this method should be limited to settings where there is point recharge directly into a cave stream.

7.2.2 Hydraulic Tes1ing Methods:

7.2.2.1 A variety of hydraulic tests can also be used lo detennine the relative "connectedness" of an individual monitoring point to the fracture-flow system, connections between monitoring wells, and conneclion 10 the site being monitored. Any hydraulic testing program requires careful design because of the discrete nature of high-conductivity zones in fractured-rock and karst aquifers. Ideally, monitoring wells should intersect the producing z.ones that are more likely to carry contaminants from the sit e. However, in some cases it may also be necessary to monitor the matrix portion of the aquifer.

7.2.2.2 Packer lests and borehole logging techniques can help locate both high-conductivity and low conductivity zones within the aquift'.r (see 6.8.3). Pumping tests can then be designed to test the connections between various parts of the sy tem (57). If poS5ible, a pumping well could be placed at the source of contamination and the response of indi-,·1Ju;il nion1toring weils tu pumping (both r;itc of response and overall drawdown) could be used 10 determine connel:-tion to the monitoring site. Sometimes more distant wells will respond more quickly than nearby wells, indica ting tha1 they are better connected lo the pumping well. Any drawdown indicates that the monirnring point is connected to the pumping well; however. it is difTicull to use drawdown 10 assess the degree of connection. Small drowdowns could indic.ite a weak connection or they could indicate Iha! the connected wne is highly transmissive (and thus difficult to draw down).

7.3 *Monitoring* We/is-Monitoring wells arc the method of ground-water monitoring required by fcdernl and state regulatory agencies and should always be considered as possible monitoring points in a karst or fractured-rock aquifer. Boreholes drilled onsite Dr olTsite 10 obt.,in geological information can be converted to piezorneters since most ground-water monitoring plans include the installation of piezometers in order lo determine the variation in hydraulic head. The piezomt:ter.; can thc:n be considered as temporary or surrogate monitoring wells. Jf any of the piezometers later prove to be capable of providing ground-water samples representative or lhe water draining l"rom the site. ,hey .:an be converted to, or replaced by, true monitoring we!ls that meet regulatory standards.

7.3.1 *Placemenr of ;',fonitoring* Welts-Placement of monitoring wells should be guided by interpretation of the data gathered in the site characterization (see 6.3 through 6.9). If the aquifer is uniformly and densely fractured, monitoring well placement, construction. and development are similar to that for granular aquifers (see Practice D 5092 and Refs (58 and 60). Diffcren1 placrn1ent and construction techniques are necessary for aquifers charactcriz.t'.d by di,-crete high-permeability zones (enlarged fractures, dissolution zones, and conduits) that carry the majority of the water. Wells placed in these high-penneability zones are more likely 10 intercept drainage from a site than randomly placed wells or wells completed in low-permeability z.ones. In sctt1ng5 where the matrix blocks have appreciable porosity, it may also be important to monitor the blocks a.s well as the high-penneability zones hecause the blocks m y function as storage reservoirs ior pollu1a11ts.

7.J.1.1 Fracture lineaments and the intersection of vertical fractures are potential sites *for* monitoring wells, especially in crystalline rocks. However, in carbonate rocks, most conduits and high-permeability zones are developed along bedding planes; monitoring wells located on the hasis of fracture-lrace and lineament analvsis are not likelv to intercept major conduits. Horizont l zones of high pe e-ability are important in determining placement of monitoring wells. If the site charac1erization has idcntilicd .:.ones of enhanced permeability (thot is, noted by borehole geophysical logs, loss of circulation when drilling, etc.), monitoring wells should be consmJctcd so as to intersect these zones.

7.3.l .2 In most karst terranes, substantial flow occurs at the soil-bedrock interface and within the subjacenl cpikarst. Wells placed acroS5 this interface or within 1he epikarst may only be intermittently satu ra ted. Howi:ver, these wells are likely to intercept the early movement of contaminants from Jn overlying source.

7.3. t.J Wells drilled ,o intersect c:ivc streams m:iy ::ilso function :u; good monitoring poin ts . ·while most geophysical 1echniques :ire incapable of detecting th tlow oiwater within conduits, the natural potemial method (a rypc of spontaneous potential measurement) is the ,inly geophysical method that c:in detect Oowing water and it can sometimes be used effectively (50. 60. 6 J, 62).

'i .3.1.4 Monitoring wells arc ;ypicaily constructed within the boundaries of the site to be monitored. In fractured-rock . and karsl aquifers, the location of high-permeability zones should guide the placement of monitoring wells even if they **are** located offsite.

7.3.2 *Construction o/.'vfoniwring Wells:*

7.J.2.1 The presence of zones of enhanced dissolution can complic:ite construction of monitoring wells in" kar.;t .ind fractured-rock aquifers. Drilling methods and well construction techniques should be chosen so as to minimize loss of drilling fluids, cuttings. or construction materials to the formation. Air-rotary drilling *is* one possibility if circulation can be maintained and risk of partial plugging of fissures can be tolerated; rotary drilling with over-shot casing c:in effectively reduce loss. of fluids to a formation.

7.3.2.2 The open interval of the monitoring well should be designed to intercept zones of high-permeability. If no such zones arc present, the well should be: cased to the depth where: competent rock is encountered and left open below that. The annular space between the casing and the borehole wall should be sealed in such a way as Lo minimize loss of materials lo the aquifer. It may be possible 10 use standard well construction techniques such as a bentonite slurry or grouting to set the casing if no high-penne::ibility zones are present.

7.3.2.3 If discrete high-permeability zones are encountered, the wells should be constructed .50 as to be open lo those zones. When smaller-diameter monitoring wells are placed within a larger-9iameter borehole, a gravel pack should be installed around the screen and an annular seal placed above the gravel pack. The gravel pack should be constructed of materials that will minimize anv chemical reactions with the ground-wa ter . Bentonite chips·and pellets are recommended for the annular seal because these materials are not as easily lost to the formation as are slurries of cement or bentonite.

7.3.2.4 All materials used in monitoring-well construction should meet federal regulations (63) and state guidelines. Practice D 5092 provides general recommendations for monitoring-well construction.

7.3.2.5 *DeYe/opment and Maintenance-Wells* that intersect high-perme::ibility zones frequently exhibit high turbidity if finer panicles from the fractures. conduits. and other djssolution zones are drawn into the well. These wells will require more extensive development than most monitoring wells. In many wells, turbidity may be a persistent problem, panicularly during and after storm events. If siltation is a · persistent problem, routine maintenance ro remove the accumulated sediment may be necessa ry.

7.3.J *Alternative Moniwring Points-When* tracer studies and hydraulic tests do not indic:ite :i connection between a monitoring well and the site being moni1ored. the well should be considered inadequ:lle for its intended pufl)ose: alternative monitoring points must be used. Monitoring water quality :n seeps. springs, *or* c:ive streams ;hown 10 be connected 10 the site by tracing studies is one ai1ern:11ive {31, -ID, 54) provided a waiver from existing feder.il or Stille regulations can be obtained (see i .5). Reguiators :ire incre::i.singly recognizing springs and cave sm:::irns as viable, efficient, and reliable monitoring points that meet the intent of the iaws, even though these features may be found offsite **(see** 7.5 . 31. However. whenever possible. the protocols ofloc::i.ting monitoring points at the me should be followed. Detection of comaminan!S prior to migration olTsite. the desired monitoring goal, may not be possible if the only relevant monitoring sites are offsite. However. because cave streams and seeps are natural discharge points for ground water flowing through discrete. difficult-to-locate. high-permeability zones, monimting at these olfsite sampling points may be the only appropriate and practicabJe monitoring strategy.

7.J.3. l When documenting monitoring points. wmontal and venical coordinates should be noted (see Practice D 5254), and pertinent geologic information should be recorded . Pertinent geologic information would include such things *as* identifying the formation from which a spring is discharging and noting particular lithologic and structural descriptor.; (for example, spring issues at intersection of vertical joint in limestone and bedding plane of a shale bed).

7.J.3.2 In carbonate terranes. the ratio between maximum and minimum discharge of a spring and the shape of the hydrographs are indic:nions of whether a spring is classified as an overflow or underflow spring {64). In addition. Wonhington (9) used the coer1icient of variation of bicarbonate and sulfate to determine overflow/underflow springs. This classification is imponant in asses.sing the number of potential discharge points and monitoring points for a karst ground-waier basin. If a spring is recognized as an overflow spring, it indicates the presence of underflow spring5 that carry some of the ground-water discharge. somerimes all of it when the overflow spring is not discharging. Both underflow and overflow springs must be included in a comprehensive ground-water monit0ring network in karn terranes.

7. 3.3.3 When collecting samples from alternative monitoring points, it is best to sample as close to a spring orifice or seep discharge as possible. Where possible, spring discharge should be measured and • recorded whenever samples are taken. If the discharge cannot be accurately measured, stage height is an acceptable alternative, and even a visual estimate of discharge is bener than no record at all. As in sampling a well. a visual description of the water sample should be· recorded (for ex.ample. level ofcutbidity, coloratio n. presence of iron staining, presence of oil sheen, noticeable odors. etc.) and standard field parameters ifor example. specific conductance. iemperature, and pH) should be me:isured and recorded.

7.4 *Sam pli ng' Frequency:*

7.4. l Water-quality parnmeters can be extremely variable in karst and fra.ctured-rock aqu ifers. This is panicularly true during .ind after recharge events that cause rapid changes in dischargt: :it springs or rapid changes in hyd ra u l i c he:i.d at wdls. Such events typic;illy c.iu c: hig.h-rrc:4 ucncy, high-amplitude changes in water quality . The!.e wa1er-quali1y ch:rnges ma:,, be either in-phase or out-of-phase wnn discharge peaks or with each other. ln ord r for samples to be representative of conditions in the aquifer, frequency or sampling should be selc:c\ed to rellect this inherent variability rather than at pre-specified. li1-ed intervals as *is* often dictated by regulatory programs. A general discussion of sampling rrequency is given in Ref (65).

7.4.1.1 The correct interpretation of the variation of water-quality data for determining proper sampling fre- quency cannot be done with confidence unless it is known that the results were not subject to aliasin . a phenomenon in which a high-frequency signal can be interpreted as a low-frequency signal or trend because the sampling was tao infrequent to accurately characterize the signal **(66).**

7.4.1.2 The following discussion of sampling frequency assumes that properly designed and conducted tracer tests and hydraulic tests have identified representative down-gradient monitoring points that are connected to the site and representative background monitoring sites that are not connected to the monitored site (see 7.2).

7.4.2 *Hydrographs and Chemographs-The* determination or an appropriate sampling frequency should be based on interpretation of the behavior of several physical :ind chemical parameters at springs and wells. Plots of spring discharge (or stage) and water quality as functions of time (hydrograph and chemograph analysis, respectively) have been used extensively in karst-aquifer studies **(14)** as tools for obtaining information about the ground-water flow dynamics of the kan;t system. (In aquifers where discharge is to subaqueous springs or seeps, monitoring is difficult. but possible-if they can be found.} Monitoring wells completed in fractured dolomite may also exhibit extreme temporal variations in hydraulic head and wa1er-quali ty parameters and these variations can be used to characterize ground-water flow dynamics in similar aquifers (17).

7.4.J *Con11entional Parame1ers-A* suite of easily measured parameters has commonly been used to characterize the variability of water-quality in kars1 aquifers. These parameters include discharge or head, specific conductance, temperature, and turbidity and are· recommended as a minimum set of data to be collected. They should be measured at representative monitoring points continuously, or near-continuously, for a period of several weeks to several months and **at** least until several major recharge evenl5 have occurred.

7.4.4 *De1ermining Sampling Frequency for Targel Compounds-When* monitoring pollutant releases from a site in karst or fractured-rock aquifers, the inherent variability of the system must be't:onsidered: The natural \'ariation of head or discharge, temperature, specific conductance, and turbidity can be used to select the appropriate sampling frequency for contaminant or target compounds. For a monitoring system, the most imponant question to be answered is whether the maximum concentration of the target compound exceeds an established background or regulatory-action value at the point of compliance.

7.4.5 A general procedure for detenning the sampling frequency of target compounds is uutlined below:

7.4.5.1 Plot discharge (stage) for a spring or head for a well, specific conductance. lemperature. and turbidity against time (plot all of them on t he same graph, using different vertical scales, so that they may be compared). The concinuous or near-continuous measurement of 1hese paraml!ters is necessary in order to pre"ent aliasing of the data .

7.4.5.2 Determine which parameter varies the most.

7.4.5.3 Establish the correlation and time-lag (if any) between maxima and minima of discharge (stage} or head, specilic conduct.ince, temperature. and turbidity.

7.4.5.4 Determine a sampling frequency that will capture the variability of **the** most-variable parame1er.

7.4.5..5 Sample for the target compound(s) at this sampling frequency both at the background and at the downgradient-monitoring points. Samples should be: coilected through at least one major recharge event. Th is recharge event should be near to or greater than the average unnual maximum recharge event. Samples must tilso be collected during baseflow conditions.

7.4.5.6 Plot the concentration of the contaminant compound(s), discharge (stage) or head, specific conductance, temperature, and turbidity against time for both high-flow and baseflow conditions. Establish the correlation and lag-time between maximum 1arge1 compound conct:ntration and the maxima and minima of discharge (stage) or head, specific conductance, temperature, and turb idity . These correlations determine the subsequent sampling frequencies for the target compounds.

7.4.5. 7 If the maximum target compound com:c::ntrations are measured under baseflow conditions, periodic samples collected during lowest flow conditions may achieve the monitoring goals. If maximum target compound concentrations occur during high-flow conditions, then subsequent samples for those compounds must be collected during high flow. High-flow sampling frequency should initially be based on 7.4.5. 1 through 7.4 .5.4 and modified as dat3 are collecred and interpreted.

7.4.6 This procedure may indicate an opumum storm-related sampling frequency ranging from minutes to hours for some systems; sampling at this frequency is necessary through at least one major recharge event Analytical costs can be lessened by analyzing every third sample. If the contaminant concentration data plot smoothly, it may not be necessary to analyze the stored samples; if they do not, it *will.*

7.4.7 At the start of a recharge event, it is impossible to know how signilicant it will be. At ifs middle or end. ii is 100 late to collect samples that will characterize its beginning. Accordingly, it is always necessaT)' to commence sampling at the start of an event. After the event. the decision to analyze or not to analyze the samples should be based on professional judgment and evalua1ion of the signilic.ince of the even1.

7.5 Meeting Regulator_v Goals:

7.5.I Regulatory agencies require ground-water moni-10ring wells as a means of detecting stalistically significant changes in water quality resulting from releases to ground water by various operations. However. alternative monitoring points such as springs and cave streams, shown to be draining from the site, may provide the most representative ground-water samples in some seuings, and have bet:n required in some states (see 7.3.3).

7.5.2 *Current Federal RegulGlion.s-* The Code of Federal Regulations (CFR) that addresses ground-water monitoring and corrective action at hazardous-waste-disposal sites can be found in Re((67) (40 *CFR* Subpan F §§ 264 90 to 264. IO I .:ind 40 CFR Subpan B § 270. l 4(c)). These regulations contain specific infonn:nion on monitoring ground-**water** quality(§ 264) and reporting requirements based on a comprehensive **site** investigation (§ 270). Section 264.97 specific:illy lists ground-water monitoring requirements that must be met in order to satisfy the requirements of§ 264.98, Detection Monitoring; § 264.99, Compliance Monitoring; and§ 264.100, Corrective Action. Section 270. l 4(c}, *Additional Information Requiremems,* provides *for* specific information to be compiled and submitted in order to meet the provisions reQuircd under§§ 264.90 through 264.10 I (66).

7.5.3 *Modifications of Curr<:nt Regula1.ian.r-Recem* pro• gram evaluations have shown that specifically requiring certain items (for example, monitoring wells) has led to the development of inadequate ground-water monitoring systems that arc designed solely to meet regulatory guidelines. The U.S. EPA is currently considering new, more llexiblc guidelines/regulations that allow the use of seeps, springs. and cave streams as monitoring points to supplement a monitoring-well network. Alternative monitoring points would have to meet the performance criteria described in Ref (67} § 264.97 [for example, monitoring wells at the point of compliance Ref (66) § 264.97(a)(2)J and the use of such alternative monitoring points would be based on a site investigation designed to assess the hydrogeologic conditions of the site. These new procedure5 have been outlined in Reis (63, 67, 68).

7.5.J. l Alternative monitoring schemes have been proposed and implemented at some facilities regulated under the Resource Conservation and Recovery Act (RCR.A), where hydrogeolo&ic conditions did not conform to the porous-medium approximation. The reasoning behind such variances was that a monitoring system consisting solely of monitoring wells that are unable to provide ground-water samples representative of **a** given site would not meet the intent or spirit of the law. However, monitoring ground•water quality at allernative, offsite monitoring points, while violating the letter of the law (because the points are otTsite), would meet the intent and spirit of the law. Such variances from RCRA regulations are considered acceptable for existing and interim status facilities. Variances have not been allowed for a new facility because § 264:97(a)(2) (66) stipulates that monitoring must be conducted at the point of compliance (for example, the unit boundary or facility bounda ry).

8. Keywords

8.1 carbonate aquifers; fractured,rock; ground water; ground-water monitoring; ground-water sampling; karst; springs

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Attachment 4

Table 1. Summary of Dye Trace Lengths, Gradients, and Estimated Menn Velocities for the First Arrival of Tracer Dyes

From	To	Distance **(feet)**	Elevation loss **(feet)**	**Mean** Gradient **(feet/mile)**	Est. Mean Velocity **(feet/day)**	**Trace** number
Beaver fa! ls	Mop Spring	2,860	70	129	240	OJ-01
North Quarry	Active Spring	855	150	923	114	OJ-02
NFSR 20/27 intersection	Chango Spring	330	100	1600	>JJO	03-03
Bear's Plunge	Cataract Spring	3,270	530	855	65<-i	03-04
Slide Cave	Cataract Spring	3,030	580	1,010	606	03-05
Devil's Canopy	Boiling Spring	5,020	600	630	>200	03-06
Sign Sink	Mop Spring	4,S00	IJO	275	230	03-07
Historian Cave	Mop Spring	1,730	90	275	1,275	03-08
Ca bbage Patch Sink	Honking Spring	3,500	280	422	J 85-875	03-09
Line of Sinks	no dye detected					03- 1 0
Neck Lake Overlook	no discharge point identified					03-11
Dry Stream	Grass Spring	1,090	230	1,114	l,o90	03-12
Flyhatch Spring	not a groundwater trace					03-13
Bearcat Spring	not a groundwa1er trace					03-14
Road Sink	Honking Spring	4,810	330	362	8,225	03-1 5
South Quarr y	Cata ract Spring	7,280	750	544	1,820	03- 1 6
Sllort Trace Sink	Fat Man Spring	690	40	306	-8,000	03-17
Brusby Creek	Cataract Spring	l 0,050	940	494	3,350	03- 1 8
Log Hole	Boss Spring	5,160	330	] 38	1,720	03-19
Log Hole	Large Spring	5,555	650	618	1,234	03-19
Log Hole	Cold Spring	5,655	650	607	1,200	03-19
Blueberry Sink	Fat Man Spring	2,490	360	763	950	03-20
Rack Crack	Honk i ng Spring	5,220	J00	303	1,8 l 5	03-21
Milepost 99	Honking Spring	5,720	390	360	2,860	03-22

The investigation also developed considerable water quality and flow data for the study area. The data is useful for se lecting locations that may requi re more intensive mon itoring. The in ves tigations als o provide a base li ne to assess potential impa cts due to changes in land use. The data are appended to the dye tracing report provided in Appendix A.

USGS
science for a changing world

Incooperation with the Kentucky Department o1 Agriculture ,.f-1/4,c Itwte 1 5 Pesticides

PESTICIDES AND NUTRIENTS IN KARST SPRINGS IN THE GREEN RIVER BASIN, KENTUCKY, MAY-SEPTEMBER 2001

MAJOR FINDINGS

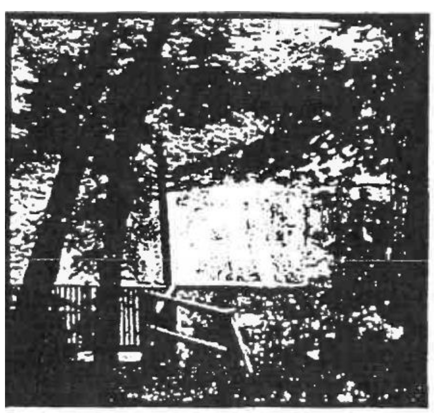
- Nine different pesticides were detected in eight k.irst springs sampled in the Green River drainage hasin .
- The five most frequently detected pesticides at all springs were atrazine (JOO percent), simazine {93 percent) , metolachlor {80 percent), tebuthiuron (66 percent), and prometon (58 percent).
- The pesticides detected were not necessarily the pesticides most heavily applied in the Green River urainage basin.
- Nitrite plus nitrate-nitrogen concentrations did not ex.ceed the U.S. Environmental Protection Agency (USEPA) drinking water standard (10 milligram per liter) at any of the eight spri ngs.

INTRODUCTION

Springs located in the Green River Basin, Kentuck-y, are valuable natural resources and impor1ant sources of public and domestic w.ater supplies. Ground water and springs in the Green River Basin potentially are vulnerable to increased concentrations of pesticides and nitrates associated with agricultural activities, such as pesticides and nitrates. because of the presence ofkarst topography. The karst topography can allow rapid recharge of flow through fractures in rock and solutional conduits, providing little opportunity for natural filtering to occur. Understanding the extent and potential severity of ground-water contamination in karst areas is therefore crucial to protecting the public and water resources in the Green River Basin.

There is polential for ground-water contamination associated with the use of pesticides and fertilizers in the Green River Basin because of the extensive agricultural development of land. By sampling the water quality of karst springs and examining the use and de.tections of pesticides. information can be provided to better evaluate ground-water quality and agricultural nonpoint-source pollution in the Green River Basin, and assist resource managers in the planning and implementation of nonpoint-source pollution-control programs.

In 2001, the U.S . Geological Survey (USGS) began a 5-month study in cooperation with the Kentucky Department of Agriculture to evaluate the occurrence and distribution of pesticides and nutrients in springs in the Green River Basin. This paper summarizes data on the concentrations and frequency of detection of pesticides and nutrients in samples from eight selected springs and presents pesticide sales data (pounds of active ingredient) from the year 2000 as a SU!Togate for application rn res .



Lost River Blue Hole Spring near Bowling Green, Ke ntuc ky .

FIELD AND LABORATORY METHODS

Thr:: USGS collected pesticide and nutrient samples from eight springs (fig. I and table l). Samples were collected c:very 2 weeks during May-September 200 I. General procedures for the collection of water-quality samples and equipment cleaning are described in Shelton (1994). Water samples were analyzed by the USGS National Water-Quality Laboratory in Denver, Colorado, for 50 pesticide compounds u ing methods described by Zaugg and others (1995). The laboratory reporting level (LRL) for detected pesticides are listed in table 2. A detailed discussion of LRL's can be found in Childress anJ u\hc:.r (1999). Nutrient samples (ammonia-nitrogen (NH_3-N). nitrite plus nitrate-niLrogen (NO_2 + NOr;\), total phosphorus (TP). and orthophosphate (onhoPJ) also were analyzed by th USGS National Water-Quality Laboratory using methods de.scribed in Fishman and Friedman (1989).

3604
Attachment 5 to Aley Report

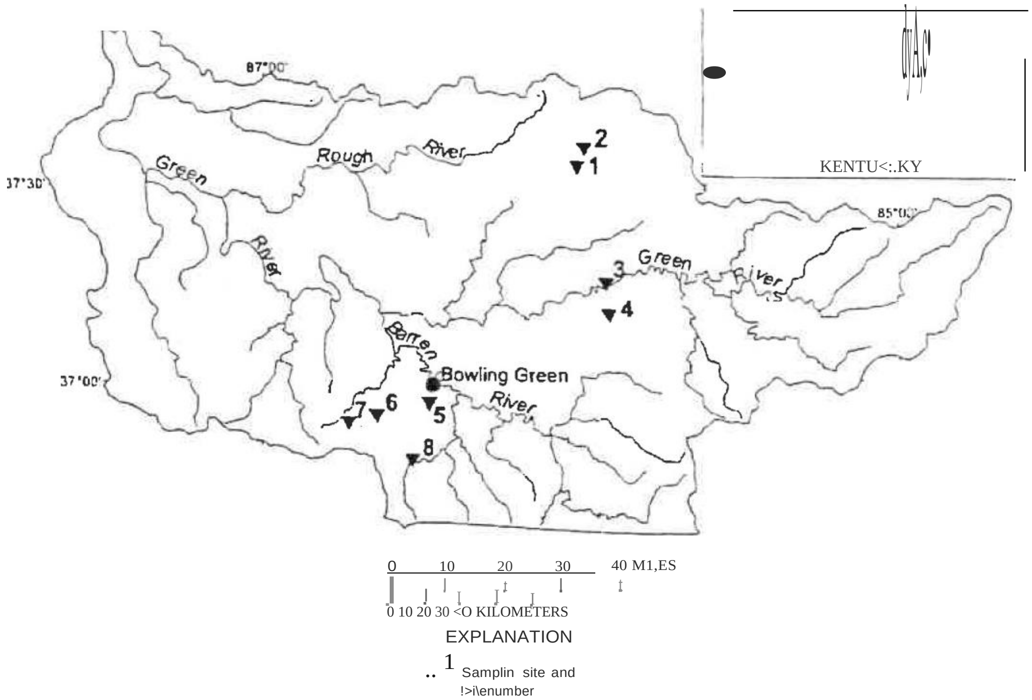


Figure 1. Location of spring-sampling sites in the Green River Bas,n. Kentucky.

Table 1. Selected spring sampling sites in the Green River Basin, Kentucky
[USGS, US. Geological Survey)

Map reference number {see fig. 1)	USGS station number	USGS station name	Lalilude	Longi1ude	Number of samples
	373320086001601	Waddel Sprin near Harcoun. Kentucky	3T33'20"N	86'00'l6"W	6
2	373608085585101	Boiling Spring al Slat Mill . Kcnlucky	37'36'08"1'\	R5 "5 R' 5 r ·w	8
3	371528085545301	Gorin Mill Spring near Munfordville. Kcn1ud:y	3rJ5'2 · ;>;	S 5.1·5y·w	h
4	37104408554200!	Hidden River Ca,·• at Horse **Ca,·c,** Kentucky	.n- 1 0•44· •:-,;	85"54"20"W	8
S	365713086282103	Los\ **Ri,er** Blue Hole SprinE near Bowling G,c.,n. Kenlucky	.,6"57' l3"N	B6 "l 8·2 r,V	8
6	365526086382SOI	Finney Sprin£ near South Union. Kt:nlucky	)6'55'26"N	86' 3.8 "-&" W	
7	36541508643500]	Crawford Blue Hole Spring near Auburn. Kenlucky	36"54'15"N	86"43 ' 50"W	7
8	364832066313701	Drnkcs Spring near WDOdburn. Kcmuc\..")'	36"48'32"N	&6"3l".1TW	8

Table 2. Summary of the concentrations, detection frequencies, and aquatic-life criteria of the detected pesticides in samples collected from eight springs, Green River Basin, Kentucky, May-September 2001
lµg/L. microgr m, per liccr; --. not cslablished)

Pesticide name	Trade name	Type of pesticide	Laboratory method repor1ing level (us/L)	Delecllon frequency. in percent (number ol samples)	Median concentration of detections (µ9/L)	Maximum concentration of detections (µg!L)	Water-quality criter1,c1 for aquatic lite (ji,g/l)
Ace1ochlor"	Harness Plus. Surpass	H<tbicide	0Jl04	14 (59)	0.00.:1	0.099	
At.r.uin	AAtre . Alred	Herbicide	.007	100 (59)	.159	7.40	•1.s
Chlorpyrifos	Brodan. Dursban	Jn CClicidc	.tr.JS	"(59)	.005	.OJ I	0 0-11
Me1olachlor	Dual. Pennant	Herbicid	.013	80 (59)	. 0.\5	J43	°7.R
Mctribuzin	LcJ.nnc. Sr:ncur	Herbicide	1};)6	, (59)	.006	.O: I	"
N:ipropamidc	De,·ri"nl. Napro uard	Htrbicide	.007	3 ())	.(11.l'/	.0 1 I	
Promc-lnr1	Prami1ol	)i erbi ri dc	01	S ! 59)	' .0 :1	C(, ,.	
Sim.:izine	A qu;1 ini:. Pri nct-p	Herbicide	.01 I	93 ,.59)	.019	...'10	' 10
Tc'b11th1ur(1n	Spike . Tcbusan	H<ibiciJo	.1116	66 159)	, ·.0 11	.1143	,, f,

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Approximately 30 percent of the samples analyzed were quality-control samples. which included 12 field blanks, 7 concurrent replicates, 4 field spikes. and I laboratory blank. Field blanks were collected to ensure that no contamination occurred during sampling and processing of the samples. *A* blank is a type of water solution that is intended to be free of the analytes of intere l. Concurrent replicates were used to evaluate the reproducibility of the laboratory analytical techniques. A concurrent replicate is **a** type of sample collected simultaneously by use of two or more samplers. Field-spike samples were used to determine bias as a result of matrix interference. *A* spike is a type of sample in which known amounts of pesticides are added to.water. Quality-control-sample results indicaled good laboratory performance and no systematic contamination.

PESTICIDES

Pesticides have become an integral part of controlling insects, weeds, fungi, and bacteria in both agricultural and urban settings. The use of pesticides has increased over the last 40 to 50 years, which has resulted in increased crop production and controlled public health hazards (Larson and others, 1997); however, there- are increased concerns about the possible harmful effects of increased pesticide concencrations on the environment and human health.

Of the 50 pesticides analyzed, 8 herbicides and I insecticide were detected at or above a common method reporting level (CMRL) of 0.01 micrograms per liter (pg/L) at the 8 springs. A CMRL allows the detection frequencies of pesticides to be compared to e,ich other. Adjusted data. using a CMRL, were used to compare detection frequencies. whereas unJdjusted dat:.t were used in statistical analyses. Th..: detected pesticides in the springs were atrnzine. simazim:. metolachlor. tebuthiuron. and promcton (!ig. 2). B:.1scd cin estimated pesticide sales darn for agricultural applications in 2000. a total of i .5 million pounds of herbicides (fig. 3) and 18,000 pounds of inse.cticides (fig, 3) were applied in the Green River Basin (Ernest Collins, KenLUcky Department of Agriculture::, written commun., 2001).

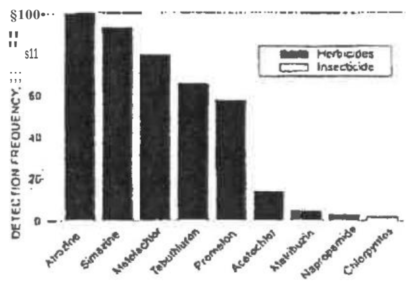

Figure 2: Detection frequencies for selected herbicides and insecticides at eight spring-sampling sites in the Green River Basin, Kentucky.

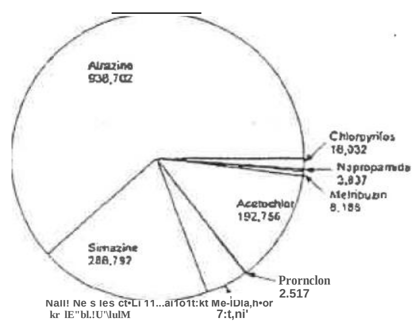

Figure 3. Estimaled sales data for 2000 (in pounds per active ingredient) of selected herbicides and insecticide in the Green River Basin, Kentucky.

The pesticides detected were not necessarily !he pesticides most heavily applied (in pounds of active ingredient) in the Green River Basin. Acetochlor, a restricted-use pesticide, 1,vas found in only 14 percent of the samples, but was one of 1he most heavily applied pesticides (table 2 and fig. 3). Jl shou Id be noted that pesticide-sales data were used as a surrogate ror actual pesticide-application rates. Whereas sales data are a good indication of intended use, they do not necessarily reflect actual pesticidi! use (Barbash and Resek. 1996).

Only six of the listed pesticides in table :2 have an ;iquatic-life criterion assigned to them by the USEPA (1999a) or the Canadian Council of Resource and Environment Ministers (Environment Canada, l 999). An aquatic-life criterion is a numcric,il crircnnn designed tu pr,.;vcnl unacceptable long-term (years and decades) and shorHenn (days and weeks) effects on aquatic organisms. Atrazine, a restricted-use pesticide, wa.s the only pesticide detected at concentrations greater than its established aquatic-life criterion of 1.8 µg/L (table 2).

The maximum conce.ntrations of four pesticides were detected in samples collected at Finney Spring: atrazine (7.40 ,ug/L); metolachlor (0.343 µgnJ; napropam.ide (0.011 ,ug/L); and simazine (0.210 _ug/L) (table 2) Maximum concentr:.11ions of acetochlor (0.099 µg/L), chlorpyrifos (0.011 µg/L), metribuzin (0.01 l µg/L), anc.l t,.;buthiuron (0.043 µg/L) were observed **at** Lost River Blue Hole Spring. The maximum concentration of prometon was observed at Gorin Mill Spring (0.468 _ug/L). Median concentrations of selected pesticides ranged from 0.004 to 0.159 µg/L (table 2).

NUTRIENTS

More than 60 water samples wen; collected at the eigh1 .springs and analyzed for nutrient species: ammonia-nitrogen (NHrN), nitrite plus nitrate-nitrogen (NO_2+NOy N). total phosphorus (TP). and orthophosphate (orthoP). Concentr,llions of NH_3 - >i wt:1c al or below the method reporling level of 0.04 milligram per liter (rng/L) of N (fig. 4a). except for Crnwford Blue Hole and Finney Spring.

!\itritc ::ind ni1ratc are innroanic io11 produced during various stages of the nitrogen cycle. Nitrale is the most predomin,lle ion in well-oxygenated wmcr because of 1he rnpid oxidation of ni1ri1c. Concentrations of nitrate

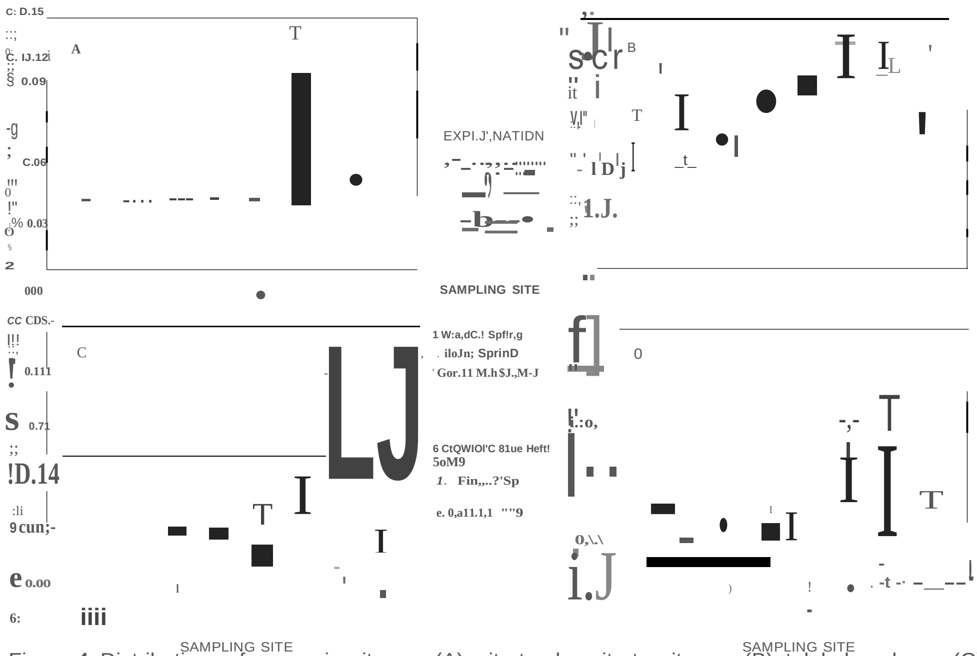

Figure 4. Distributions of ammonia-nitrogen (A), nitrate plus nitrate-nitrogen (B), tolal phosphorus (C), and orthophosphate (D) concentralions in eight springs in 1he Green River Basin, Kentucky.

greater than l O mg/L in drinking water can have adverse human-health effects, especially to infants whose digestive systems convert nitrate to nitrite thereby reducing the oxygen-carrying capacity of blood and resulting in methemoglobinemia (blue-baby syndrome) (U.S. Environmental Protection Agency, 1999b). Nitrite plus nitrate-nitrogen concentrations from the eight springs ranged from 2.92 to 8.39 mg/L (fig. 4b). The highest NO 2+NOr N concentration was measured at Finney Spring (fig. 4b). This high.concentration could be a localized effect possibly caused by land use; further study_ is needed to determine this effect.

Although there is no established aquatic-life criterion for dissolved phosphorus, the USEPA recommends a maximum concentration of total phosphon1s of 0.1 mg/L to discourage excessive growth of aquatic plants and algae. Total phosphorus concentrations in 13 percent of the samples were greater than 0.1 mg/L. The highest TP concentration among the springs sampled was 0.28 mg/L in Finney Spring (fig. 4c). The high TP concentrations possibly were associated with high values of turbidity measured at this site because phosphorus can ad orb to s-cdiment particles. The median concentration of TP for all springs sampled was 0.06 mg/L. Orthophosphate concencrations ranged from 0.02 to 0.18 mg/L (fig. 4d).

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OZARK UNDERG RO UN D LABO RATORY
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Attachment 6

GROUNDWATER TRACING STUDY

OF

STUPPERICH SPRING AND VICINITY

February 4, 1998

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Thomas Aley, PHG & CF
Ozark Underground Laboratory

An investigation conducted for Dr. John Brown, AIR, Inc., 7900 O' Neal Drive, Columbia, MO 65202.

Introduction

This report details the results of a groundwater tracing study conducted in an area south of Fordland, Missouri. HerbiciJ-: was pr:.tyeu u11 a ;:-01\·c lir:e -.:-0rridur in 'lie '.::T 1/4 of Section 25, T28N, Rl 9W of Webster County, Missouri. The area which was sprayed was located along the east side of a county road which runs generally north-south through portions of Section 25 and 36 T28N, Rl 9W. The councy road basically follows an unnamed valley (which in this report I will call County Road Valley) for most of its length. It is my understanding that, subsequent to and shortly after the herbicide spraying, plants in a greenhouse business located in the NE 1/4 of Section 36, T28N, RI 9W in Christian County, Missouri, were damaged or died It is also my understanding that plant damage or mortality persisted or occurred from time to time for some appreciable period after the initial onset of phytotoxicity.

The source of water for the greenhouse operation was a perennial spring which I will call Stupperich Spring in th.is report Th.is spring discharges at the base of a hill on the west side of County Road Valley. This spring has perennial flow as is demonstrated by the presence of watercress *(Nasturtium officinale)* in the waters which discharge from the spring. I estimated the flow rate of the spring at 30 gallons per minute on January 6, 1998.

The correspondence between the herbicide spraying and the plant damage and/or plant kills at the greenhouse operation clearly suggested that the powerline spraying caused the damage. However, an independent hydrological verification that the powerline which was sprayed with herbicide traverses an area which contributes groundwater to Stupperich Spring was desired.

Hydrogeologic Setting

The geologic map of Webster County, Missouri (Thomson, 1986) indicates that the herbicide spraying was primarily done in areas widerlain by the Pierson Formation. This is primarily a limestone unit and is the host rock for many springs and caves in Webster and Christian Cow1ties. The highest elevation portions of the sprayed area are underlain by the Elsey Formation; this is a limestone unit v,ith abundant chert. Beneath the Pierson Formation is the Northview Formation which is a unit with appreciable amounts of shale. Permeability of the Northview Formation is typically low. As a result, many springs in the region discharge from locations near the base of the Pierson Formation; this is the setting for Stupperich Spring.

Karst groundwater systems are those located in soluble rock areas (such as limestone areas) in which there is appreciable groundwater movement through dissolved our openings in the bedrock. Karst areas commonly have hydrologic features such as sinkholes, losing streams, and springs. County Road Vallcey and SLUTounding]ands are clearly located in a karst area: there are many sinkholes. springs. caves, and losing stre:uns in the area. Furthermo re . Counr: Road Va.lley :s oh ·,c L: s l y ı !o::-i r ı!:! ·,Lr;.::.:.n·

valley. One of several indication of this is a spring which we have caHed Powerline Spring. [t is located on the powerline corridor and immediately adjacent to the eastern edge of the county road. This spring is located about l 8 inches above the bonom of the intermittent stream channel that flows on the east side of the county road. Powerline Spring had an estimated flow rate of 30 gallons per minute on January 6, 1998. Water from this spring flows toward the south along the road ditch On January 6, 1998 the entire flow of this spring was disappearing into the groundwater system between the spring and a point approximately 300 feet downstream.

For locational purposes we numbered all electric power poles located along County Road Valley and south of an east-west trending road passing through Section 25. For simplicity in explaining locations we will assume that the powerline runs in a north-south direction, and that the northern-most pole is Pole I. Pole 9 is the southern end of the electric line along which the herbicide spraying occurred. Pole 9 has a transformer hung on it and is the pole immediately north of the mobile home to which this power line is run. Powerline Spring is located between Poles 6 and 7 and is approximately 90 feet north of Pole 7. All distances are approximate and are used to help identify the locations of particular features of interest.

Groundwater Tracing Study

A groundwater tracing study *was* conducted to verify that lands on which herbicides were applie for powerline purposes do in fact yield waters to Stupperich Spring.

Sampling Stations

Six sampling stations were established for the dye tracing study. They were as follows:

Station I. Rockledge Spring. This is a small interrnittent spring located about 100 feet west of the road which traverses County Road Valley. The spring can be easily reached by leaving the road between Poles 8 and 9. The estimated flow rate of this spring on January 6, 1998 was 6 gallons per minute.

Station 2. Powerline Spring. This is an intenninent spring described earlier; it is readily visible from the county road. This spring is located between Poles 6 and 7. The estimated flow rate on January 6, 1998 was 30 gallons per minute.

Station 3. West Side Spring. This spring has two primary discharge points; they are both 15 to 20 feet in elevation above the floor of the County Road Va[ley. West Side Spring is located on the west wall of County Road Valley and essentially straight across the valley from ' Stat ion 4 (Bubbling Spring). The estimated flow rate of West Side Spring on January 6, ! 998 was l 35 gallons per minute. The spring has a small amowlt of watercress present. so there is apparently a very small amount of perennial flow from this spring.

Station 4. Bubbling Spring. This _imenninent spring is located about 550 feet south of Pole 9 on the east side of County Road Valley . The spring discharges immediately adjacent to the road from a pool that is about two feet in elevation above the road ditch. The es,imated flow rate of this spring was 60 gallons per minute on January 6, 1998.

Station 5. Srupperich Spring. 1b.is perennial spring discharges from the base of the west wall of County Road Valley and then Bows through a 30-foot long spring branch to enter the channel of the stream which traverses the valley. Stupperich Spring is located. about 1,800 feet south of Pole 9. The flow rate of this spring was estimated at 30 gallons per minute on January 6, 1998.

Station 6. Main Creek Upstream of Srupperich Spring. Tius station was established to monitor County Road Valley at a point upstream of the muurh of lht! -,pring branch from Stupperich Spring.

Background Sampling

Background sampling was conducted prior to the introduction of any tracer dyes. Ac6vated carbon samplers (also called charcoal samplers) were placed a, all six of the sampling stations on January 6. 1998 and were collected from these stations on January 8. 1998. In addition, warer samples were collected at all six of the sampling stations on January 8, 1998. All samples were analyzed for the presence of rhodamine WT arid eosine dyes. There was no detectable eosine or rhodamine WT dye in a.ny of the backgroWld samples. Furthermore, there was no reason to expect any extraneous dyes in the area. The background sampling demonstrated that there were no tracer dyes present in the study area prior to our dye introductions.

Dye Introductions

On January 8, l 998 Tom Aley introduced Jye for Trnce 98-0 l rhis trace involved the introduction of0.l pounds of eosine dye mixture dissolved in 0.7 quarts of water. The 0.1 pounds of eosine dye mixture is approximately 75% dye and 25% diluent. Eosine dye is also knov,rn as Acid Red 87; CI Number 45380 . The eosine dye mixture was introduced in a small stream channel within the sprayed corridor. The dye introduction point for Trace 98-01 was between Poles 4 and 5; the dye introduction point was about 35 feet south of Pole 4. There was no flow in the stream channel; the dye was introduced into the gravels wbJch typify the stream channels which cross ;i.nd run along the powerline corridor in which the herbicide spraying occurred. Eosine Jye for Trace 98-01 was introduced on January 8, 1998 at 5:45 PM .

On January 8. 1998 Tom Aley introduced dye for Trace 98-02. This trace involved the introduction of 0.25 pounds of rhodamine WT dye mixtu re . The rhodamine WT dye mixture is approximacely 20% dye and 80% diluting agent. Rhodarnine WT dye is also k...-1.own as Acid Red 388: there is no assigned CI Nwnber. The rhodamine WT dye mixture was introduced into the springbr::i.nch flow from Powerline Spring t ;:i p int about 10 feet downstream of trus spring . The flow rate at the time of dye inu;oduction was estimated **at** .30 gallons per minute . Rhodamine *'NT* for Trace 98-02 was introduced on January 8, 1998 at 6:15 PM.

We spoke with Ms. Trudy Stupperich on January 8 prior to the dye introductions and gave her some vials for colle1:ting daily water samples. We tol<l her that these were for background sampling; we did not tell her that we were going to introduce the tracer dyes that evening. We used this approach to avoid creating a condition where someone might suggest thar Mr. or Ms. Stupperich might have tampered with the study; furthermore, e beli_eve this to be a good scientific app ro ach. In addition, the dye introductions were made after dark when nobody was present to observe any of rhe dye introductions.

Relevance of the Tracer Dyes Used

The tracer dyes used in this study were rhodamine WT and eosine. Kanwar et al. (1990) report that, based on adsorption coefficients in the literature and field experiments, rhodarnine *WT* dye is roughly 20 to 40 times more strongly adsorbed than the commonly used pesticides. Sabatini (1989) studied the sorprion and transport of an-azine. alachlor, and fluorescent dyes in alluvial aquifer sands. He found that the mobility of the herbicides atrazine and alachlor was bracketed by fluoresc in lwhich was more mobile than these two herbicides) and by rhodamine WT (which was less mobile than these two herbicides). Eosine is basically a fluorescein which has been brominated; its mobility in groundwater systems is similar to fluorescein. The tracer dyes used nre thus highly relevant to characterizing the subsurface performance of herbicides. Furthennore, the quantities of the dyes used were very small compared to most groundwater tracing work.

Rhodarnine WT has been used to study moisture uptake and tr;:wslocmion in plants (Donaldson and Robinson, 1971). Eosine was not studied by these authors, but has been used by other investigations to study moisture uptake and translocation in plants.

Sampling Results

All tables follow the atext portion of this report. Table l presents analytical results from charcoal samplers; all of these samples were collected by the Ozark Underground Laboratory (OliL). Table 2 presents analytical results from water samples collected by the OUL.

Table 3 presents analytical results from water samples collected from Stupperich Spring by Trudy S tuppe rich . On January 8, 1998, we asked Ms. Stupperich to collect a water sample from her spring about once per day beginning January 9 until the supply of sample vials was exhausted. Each vial was stored in ihe refrigerator nfter co llection . Tom and/or Cathy Aley would periodicnlly visit the Stupperich home and retrieve the collected samples plus do other sa..--npling as appropriate. We did not provide Mr. or Ms. Stupperich with any indication of the dates or times of our \·is its . \Ve die. not tell tlic:rn that dyes had been introduced wnil after we had retrieved all samples which they collected . All resulting data are fully credible; results for Srupperich Spring are consistent regardless of who made the water co llec tion .

Procedures and criteria routinely followed by the Ozark Underground Laboratory (OUL) were followed throughout this groundwater tracing study. A copy of a document detailing these procedures and criteria is found in Appendix A

All analytical graphs for charcoal samplers are included in Appendix 8. All analytical graphs for water samples are included in Appendix C.

Based upon results shov,n in T::ibles I , *2.* and 3 . the tracer dyes which were introduced for th.is study were recovered at the following sampling stations:

1. Eosine dye from Trace 98-0l was recovered from four of the six sampling stations. These were Station 2 (Powerline Spring); Station 4 (Bubbling Spring); Station 5 (Stupperit;h Spring): and Station 6 (Main Creek Upstream of Stupperich Spring). Eosine dye was present in both charcoal and water samples from all four of these stations.

2. Rhodamine WT dye from Trace 98-02 was m;oven:d from tnree of the: .six sampling stations. These were Station 4 (Bubbling Spring); Station 5 (Stuppcrich Spring): and Station 6 (Main Creek Upstream of Stupperich Spring). Rhodamine WT dye was present in both charcoal and water samples from all three of these stations.

Quality Assurance

1. Sample H0835D was a duplicate charcoal sampler for sample H0835. Sample H0836D was a duplicate charcoal sampler for sample H0836 . The mean diffen::m:c: between peak emission wavelengths for rhodamine WT in these samplers *was* 0.05 nanometers (run). The mean difference between peak emission wavelengths for eosine in these samplers was 0.0 nm. The mean Relative Percent Difference (RPD) for rhodamine WT dye concentrations was 28.5% . The mean RPD for eosine dye concentrations was 26.8%. These values are within the normal RJ)D range for analytical results for these dyes in charcoal samplers.

2. Sample H0873 was a water sample analyzed on January 26, l 998. This sample was re-analyzed twice on January 30, l 998 as samples H0873D and H0873 R. Sample H0874 was a water sample a..rialyz ed on January *26*, 1998. nus sa'l1ple was re-analyzed twice on January 30, 1998 as samples H0874D and H0874R. Samples were kept under refrigeration between January *26* and January 30: this was the approach used for storing samples which Ms. Stupperich collected and which we collected during this study. Data in Table 2 demonstrate that such storage dol:!S nae appreciably effect dye concentrations and emission wavelength peaks in the water samples. Based upon water samples analyzed on January JO, 1 998 , the me an difference between peak emissio n

concentrations was 16.7%·. 111ese values a.re with.in the normal RPO range for analy1ical results for these dyes in water samples.

ll is the conclusion of the OUL that all data collected and all analytical data are fully credible and witbn the ranges of accun:1cy normally associated with groundwater tracing studies.

Conclusions

1. Groundwater traces 98-0 l and 98-02 bnth involved the introduction of tracer dyes in the area where the powerline corridor was sprayed with herbicide. Both traces demonstrated that herbicides reaching the ground in this area were transr,orted through the groundwater system and discharged from Stupperich Spring as weU as from other springs in the area.

2. Travel times for the first arrival of tracer dyes through the groundwater system were very rapid. The first collection of samples by the OUL was made two days after dyes were introduced for the two traces. Tracer dyes were dete_cted in both charcoal and water samples at Stupperich Spring and at all other positive dye recovery stations within two days of dye introduction . A water sample collected at Stupperich Spring by Ms. Stupperich on January 9 at 1330 hours contained both eosine and rhodamine WT dyes. Tius water sample was collected 1ess than 20 hours after dye introduction. Funhermore, this water sample contained more of both of the tracer dyes than any other water sample from this sampling station. The straight-line travel distance for Trace 98-01 from the point of dye introduction to Stupperich Spring was about 2,900 feet; the figure for Trace 98-02 was about 2,700 feet.

3. On January 6, 1998 the estimated flow rate of Bubbling Spring was 60 gallons per minute. The spring was dry at the time of our visit on January 21. Powerline Spring also showed appreciable flow rate varia,ions during the study period, but it did not cease flowing during the study period. However, the absence of watercress at this spring indicates that its flow is intermittent. ln contrast, flow rates at Stupperich Spring during the study period remained relatively constant at about 30 gallons per minute. These flow patterns indicate a karst groundwater system which contains appreciable water storage: springs such as Bubbling Spring discharge water only during periods when the groundwater system is essentially full of water. Much of the water storage is within the epikarstic zone. which is a hydrologically complex network of dissolved out openings in the limestone bedrock. Stupperich Spring is a perenrual drainage point for this karst groundwater system. Karst groundwater systems with appreciable groundwater storage and periodic discharges from "overflow" spring systems such as Bubbling Spring and Powerline Spring can retain residual pollutants such as ht:rbicides for long pcri\ids of time (commonly many years) and release them as periodic pulses. Such pulses may be associated with eirher higher than average or lower than average groundwater discharge rates. Furthermore, organic chemic::il degradation rates in karst roundwater systems are routinely much slower than in soils.

4. There was abundant evidence in County Road Valley to demonstrate that herbicides sprayed in the powerline corridor would probably enter the karst groundwater system and move off-site. This evidence included: A) bare-rock exposures on the area that was sprayed, B) a smaJl sinkhole about 20 feet east of the powerline corridor near Pole 6, C) the presence of Powerline Spring within the spray corridor, and D) the absence of continuous flow in County Road VaJley upstream of Stupperich Spring under most conditions. Furthermore, the greenhouse operation at the Stupperich Sprin_g was located about 1,800 feet south of the spray corridor and in the same valley in which the spraying was conducted. There are signs in the area directing one to lhe greenhouse, and it is readily visible from the county road that passes through the area where the herbicide was used. All greenhouses need water supplies; an investigation prior to herbicide application would have indicated that the water supply was a spring which aJmost.certainly would receive recharge waters from the powerline corridor that was ultimately sprayed.

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Certification

I certify that th.is study and report were conducted by me or under my direct supervision, and that I am a Professional Hydrogeologist certified by the American Institute of Hydrology. Furthermore, ram a Certified Forester, certified by the Society of American Foresters.

Themas Aley. PHO \ 79

Table 1. Results for ch;irco.il samples analyzed for the presence of rhodamine WT and cosine I.lyes. (Samples collected by OUL)

OUL Lah #	Stalion //	Station Name	Date/Time Placed 1998	Datcffimc Rccovcrcd 1998	Rhullaminc WT Results		Eosinc Rcsulls	
					Peak (nm)	Cone. (11111J)	Peak (nm)	Cone. (1111b)
HOG91	I	Rockledge Spring	1-6 1300	1-8 1720	ND		ND	
H0704	I	Rockledge Spring	l-8 1720	I-Ill 1700	ND		ND	
1{0839	I	Rockledge Spring	1-10 1700	1-21 161 I	ND		ND	
HU692	2	Powerline Spring	1-6 1250	1-8 1725	ND		ND	
H0705	2	Powerlinc Spring	I:& 1725	1-IO 1705	ND		539.1	3930
H084l	2	Powcrlinc Spring	1-10 1705	1-21 1615	ND		539. l	-174
IIOC,93	3	~~Wcsl Sitlc Spring~~	~~1-6 1320~~	~~1-8 1735~~	~~ND~~		~~ND~~	
H0706	3	\Vest Side Spring	1-lS 1735	1-10 1720	ND		ND	
l10837	J	West Side Spring	1-10 1720	1-21 1605	ND		ND	
l1069'1	.j	Bubbling Spring	1-6 1310	1-8 17 0	ND		ND	
H0707	4	Bubbling Spring	1-8 1740	I-JO 1725	562.l	9450	539.6	831
H083ll	4	Bubbling Spring	1-10 1725	1-21 1607	563.0	124	53 9.0	2lU
HU695	5	Stupperich Spring	1-6 1203	1-s umu	ND		ND	
110708	5	Sluppcrich Spring	1-8 1800	1-10 1745	563.8	37l	539.2	37.4
110835	5	Stupperich Spring	1-10 1745	1-21 l544	563.1	142	539.2	J0.7
I-10835D	j	S!uppcrich Spring	I-JO 1745	1-21 l544	563.1	I 10	539.2	23.6
H0696	6	Main Cr. u/s of Stupperich Spr.	1-6 1210	1-8 1805	ND		ND	
1!0709	6	Milin Cr. u/s of S1upperich Spr.	1-8 1805	1-10 1750	564 3	906	539 0	83.0
HO&J6	6	Main Cr. u/s of Stupperich Spr.	1-10 1750	1-21 1548	563.0	259	539 .-1	S5.9
H08](,D	6	!\fain Cr. 1t/s of S1upperich Spr.	1-10 1750	1-21 1548	562.'J	189	539.4	42.4

ND = No Dye Detected

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Table 2. Results for water samples analyzed for the presence of rhudaminc WT and cosine dyes. (Samples collccted by OUL)

OUL Lab fl	Station II	Station Name	Date/Time Collected 1991i	Rho1lamine WT Rcsulls		Eosinc Results	
				Peak (nm)	Cone. (ppll)	Peak (nm)	Cone. (1>pb)
IH>697	I	Rockledge Spring	l-8 1720	ND		ND	
1-10710	I	Rockledge Spring	1-IO 1700	ND		ND	
H0922	I	Rockledge Spring	1-21 1611	ND		ND	
H0698	l	Powe1li11e Spring	1-8 1725	ND		ND	
H071 I	2	Powerlinc Spring	I-JO 1705	ND		532.9	2.6 3
H0875	2	Powerlinc Spring	1-21 1615	ND		532.0	0.380
H0699	]	Westside Spring	1-8 1735	ND		ND	
H0712	J	Westside Spring	1-IO 1720	ND		ND	
1!092)	)	Wes1side Spriug	1-21 1605	ND		ND	
JW701	4	Bubbling Spring	1-8 1740	ND		ND	
H07l3	4	Bubbling Spring	1-101725	570.6	4.00	533.0	I 1 2
[illegible]	4	Bubbling Spring	1-21	Spring dry, No Sample			
H0702	5	Stuppcrich Spring	1-8 1800	ND		ND	
1107l4	5	Stupperich Spring	1-10 1745	569.8	0720	532.2	0.220
1!0873	S	Stuppcrich Spring	1-21 1544	568.8	0.048	5)16	0.027
H087:ID	5	Stupperich Spring	J-21 1544	569.2	0.050	530.1	0.019
I01n3R	j	Stupperich Spring	1-21 1544	569.2	0.046	5]24	0.023
110701	(,	Main Cr. u/s of S1upperich Spring	1-8 1805	ND		ND	
H07 l5	6	Mai11 Cr. u/s of S1uppcrich Spring	1-l0 1750	570 J	0 .854	5:32.5	0 . 259
Hmm	6	Main Cr. u/s of Stupperich Spring	1-211548	569.4	0.08!	532.8	0 .0]0
H0874D	6	Main Cr. uh of Stupperich Spring	1-21 1548	570.4	0.081	531.)	0.029
H0874R	6	Main Cr. u/ of Stuppcrich Spring	1-21 1541!	569.2	0.077	530.4	0 025.

ND = NoDye Detected

Table 3. **Results** for water **samples amllyzcll for the** 11rcscncc **of rhodaminc WT and cosine dyes. (Samples** collected by **Mis.** Stuppcrich)

OllL Lab //	Station //	Stalion Name	DIlll'/Timc Collected 1998	Rhodamine WT Rcsulls		Eosinc Results	
				Peak (nm)	Cone. (ppm)	Peak (nm)	Cone . {Pllffir
H0716	5	S111ppcrich Spring	1-9 1330	570.5	2.57	53).0	O.K27
H08 ·12	5	Stuppcrich Spring	1-1 l 1000	570 .2	0 .522	511.H	0.118
H0!!43	5	Sluppcrich Spring	l-12 l I OU	57 0.l!	0.333	532.)	0.094
H0 44	5	Sluppcrich Spring	1-ll 1000	570.2	0.236	532.5	0.076
11084.5	S	Stupperich Spring	1-14 1200	569 5	0 . 160	53 l.8	0.056
H0846	5	Stuppcrich Spring	1-15 0930	570.0	0.142	531.6	0.040
1-10847	5	Sluppcrich Spring	1-16 0900	570.&	0.10)	5)0.9	0.039
110848	5	Stupperich Spring	l-17 0800	568.8	0.086	532.4	0.034
H0849	S	Stupperich Spring	1-18 0900	570.2	0,089	531.J	0.0]0
1-101\50	5	Stupperich Spring	1-190900	570,4	0.081	530 .8	0 .031
110851	5	Stupperich Spring	1-20 I JOO	569.2	0.056	532.4	0.019
H0852	5	Sluppcrich Spring	1-2! I JOO	568.4	0.046	532.0	002()