Different Types of Break-Through Curves

by

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Outline

1. Dendritic Conduit Flow
   a) Normal To Low Flow
   b) High Flow
2. Anastomosing, High Transmissivity Zones
3. Vadose Zone Flow
4. Mixed Flow Systems

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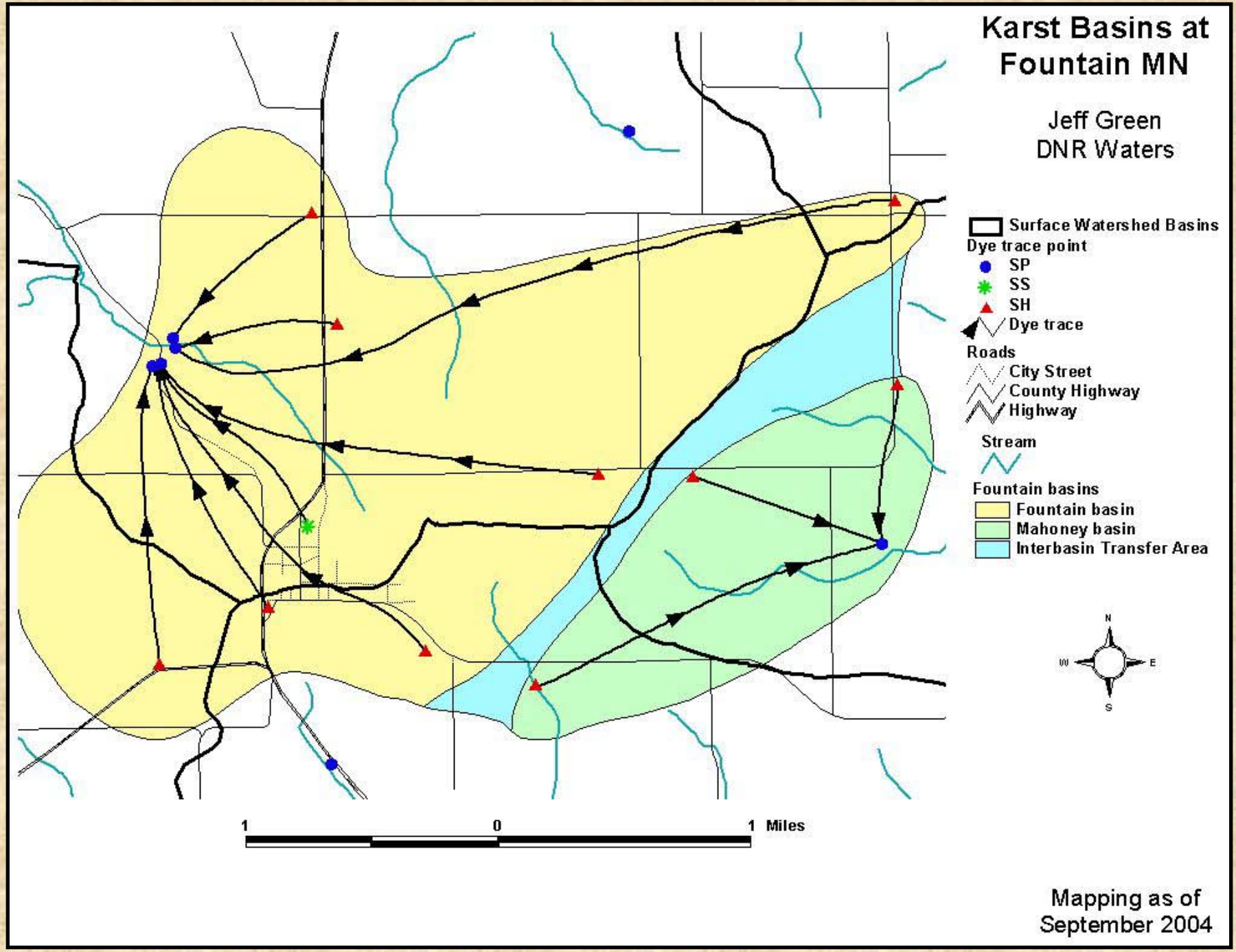
Karst Basins at Fountain MN
Jeff Green
DNR Waters
Surface Watershed Basins
Dye trace point
SP
SS
SH
Dye trace
Roads
City Street
County Highway
Highway
Stream
Fountain basins
Fountain basin
Mahoney basin
Interbasin Transfer Area
N
W
E
S
1
0
1 Miles
Mapping as of
September 2004

Water Tracers

- A fundamental tool for measuring flow velocities in the rapid flow portions of aquifers.
- Fluorescent dyes have proven to be useful for tracing in karst aquifers.
- In addition to flow velocities, tracers can yield information about the nature of the subsurface flow path.
- Questions have been raised about the safety of fluorescent dyes by regulators in some states.

Water Tracers

- After over a century of routine usage with no reported damage to biota or humans research has identified two species that are truly endangered by fluorescent dye traces (S. Johnson, 2005):

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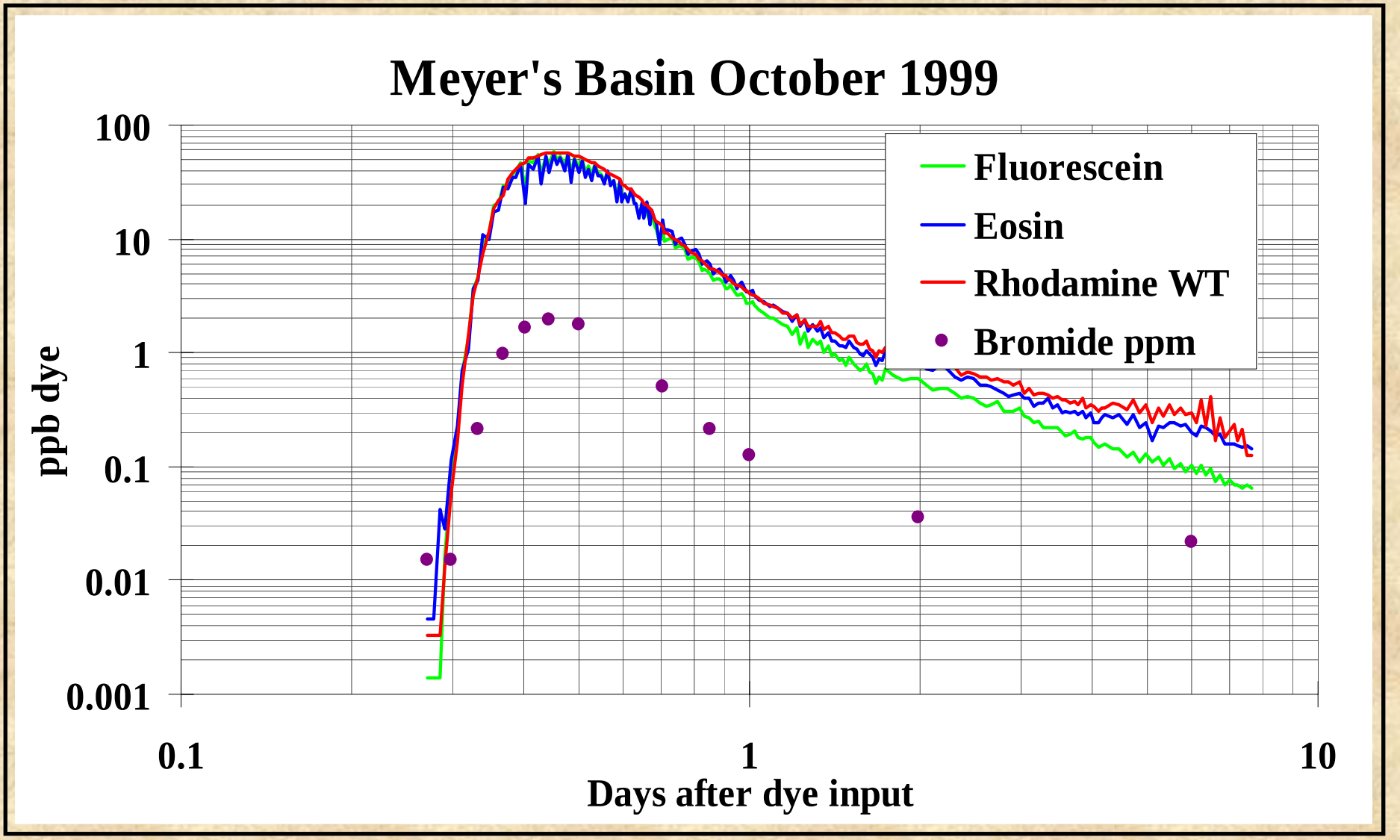
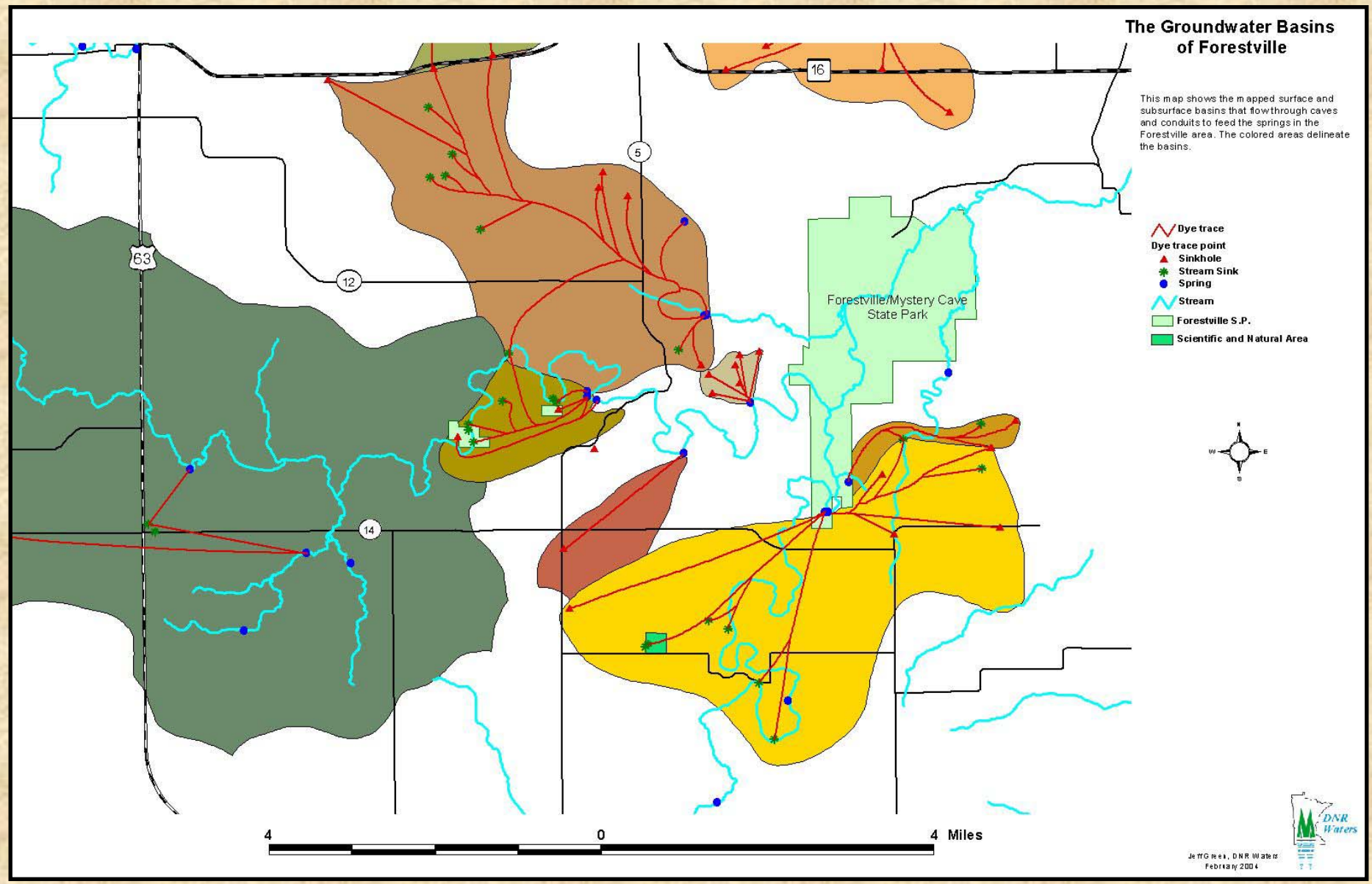
Bos sanctus

Postulatio falsus


Meyer's Basin October 1999
100
10
1
0.1
0.01
0.001
ppb dye
0.1
1
10
Days after dye input
Fluorescein
Eosin
Rhodamine WT
Bromide ppm

The Groundwater Basins of Forestville State Park



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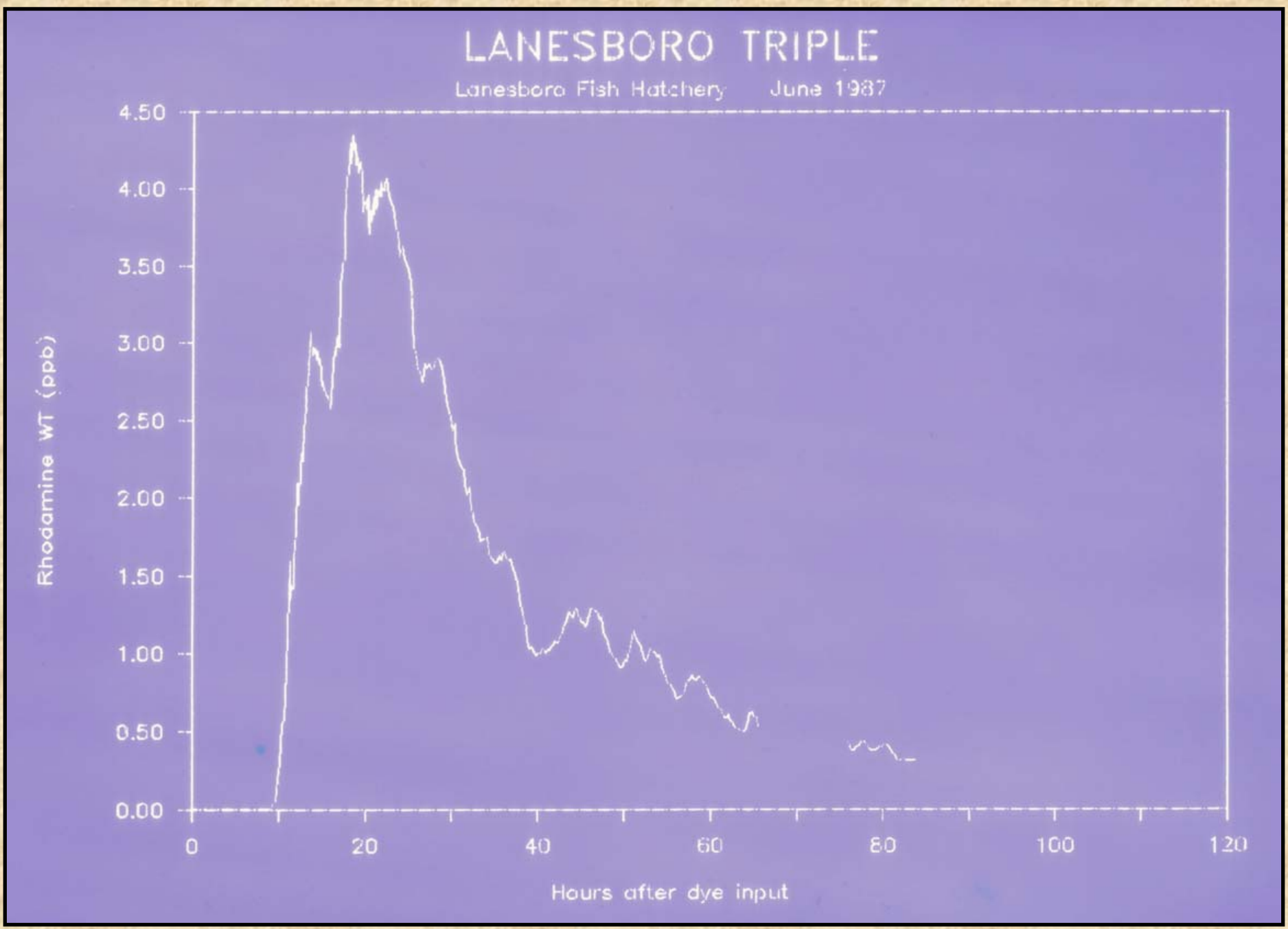
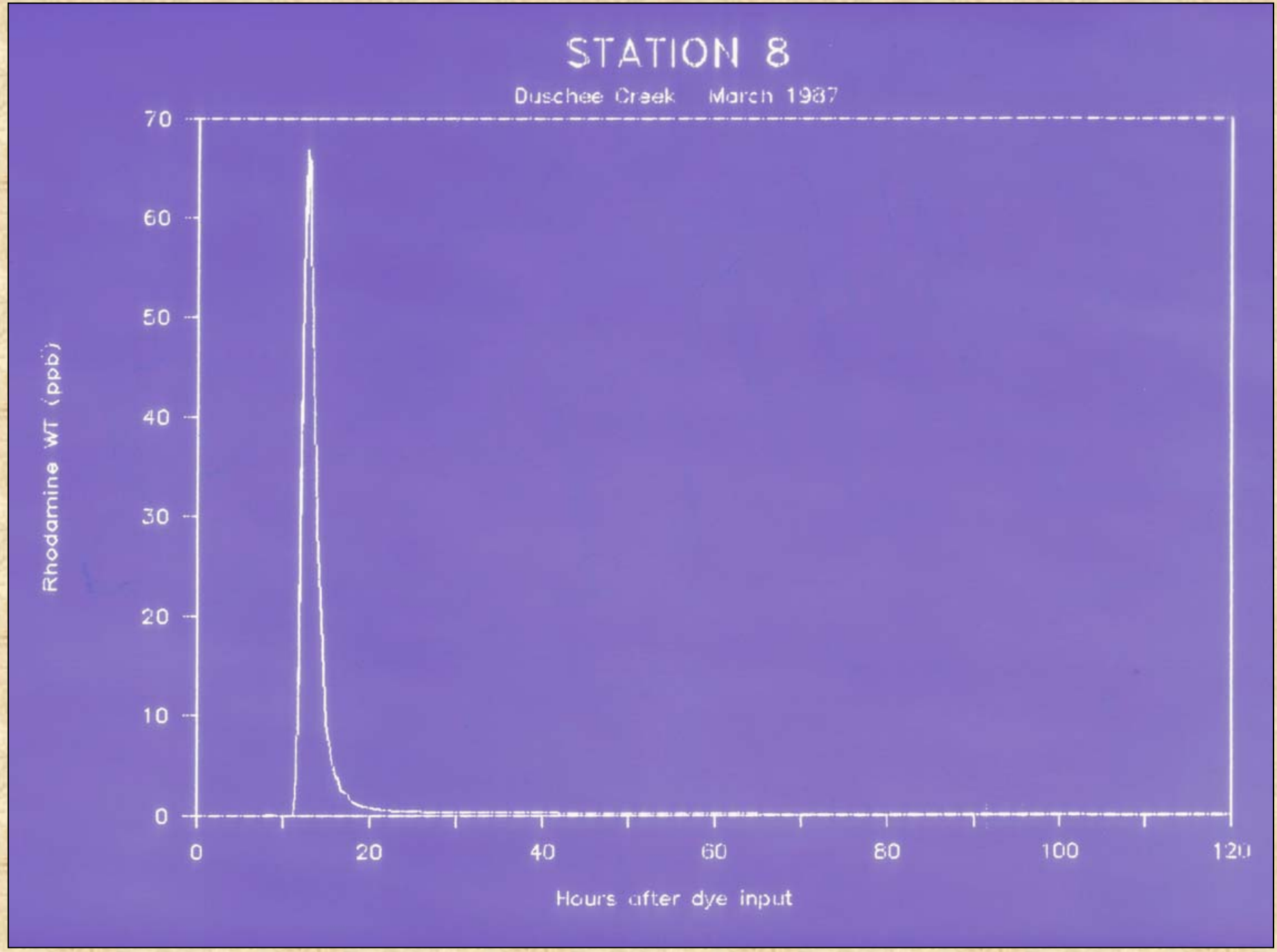
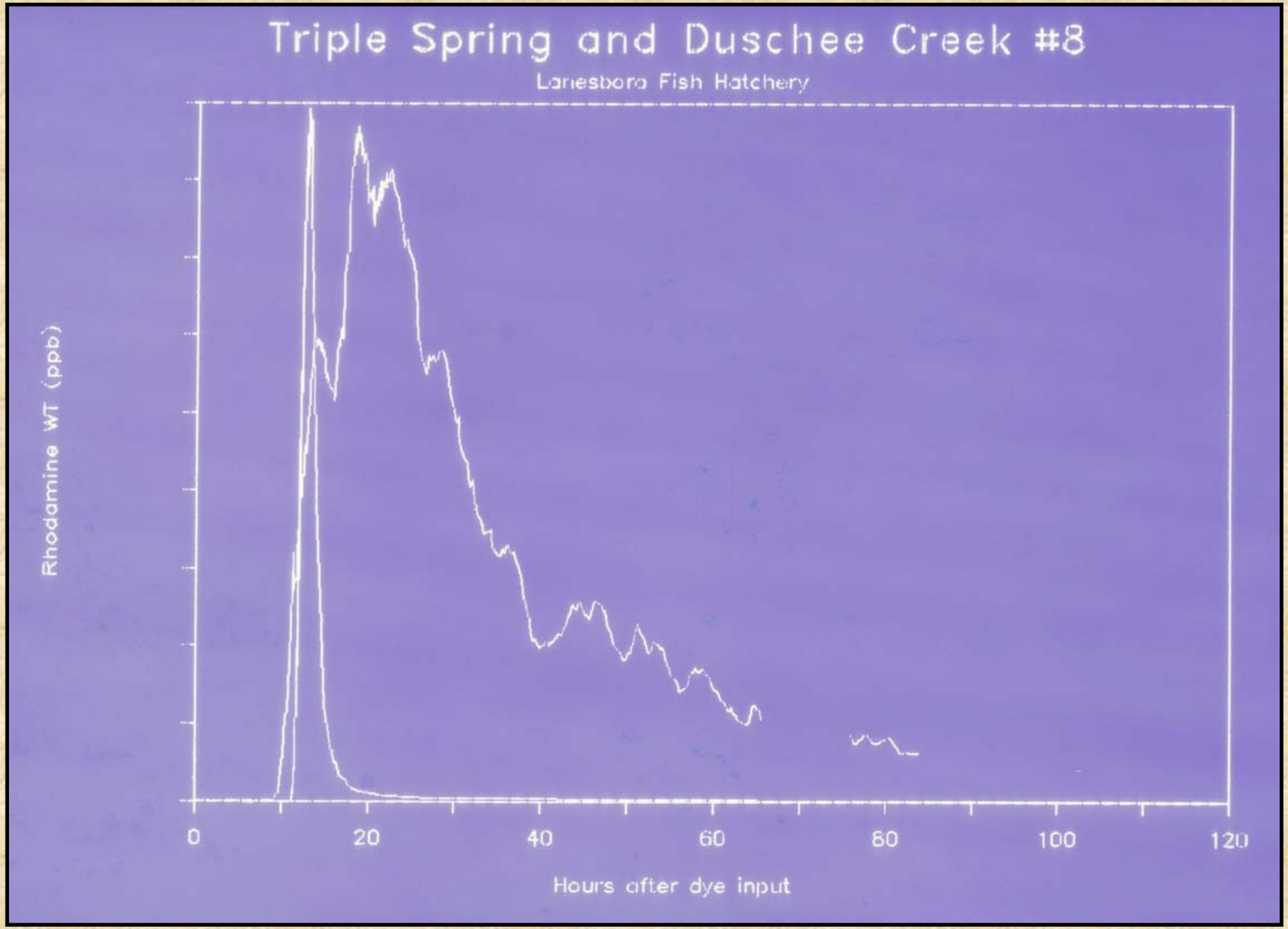
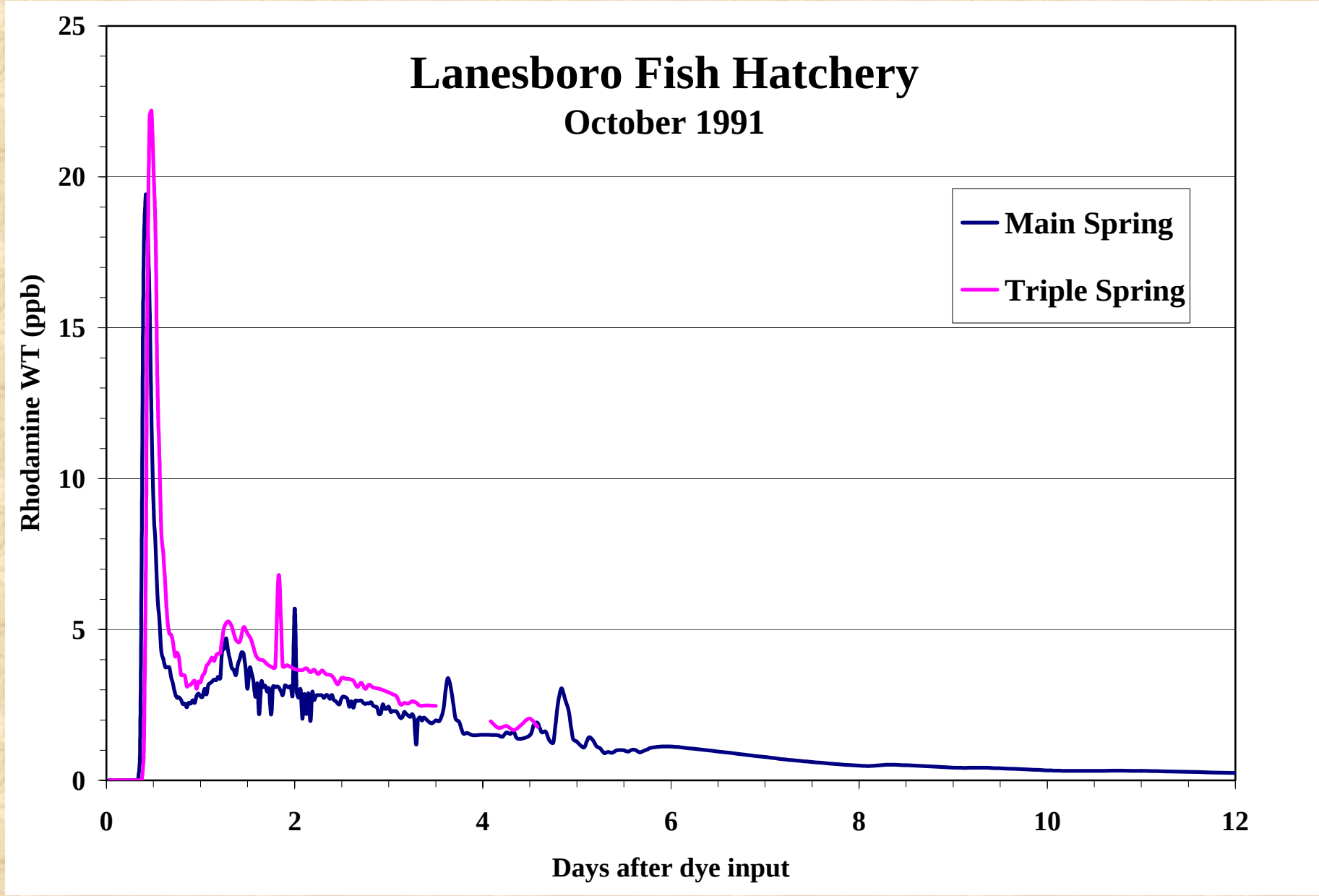
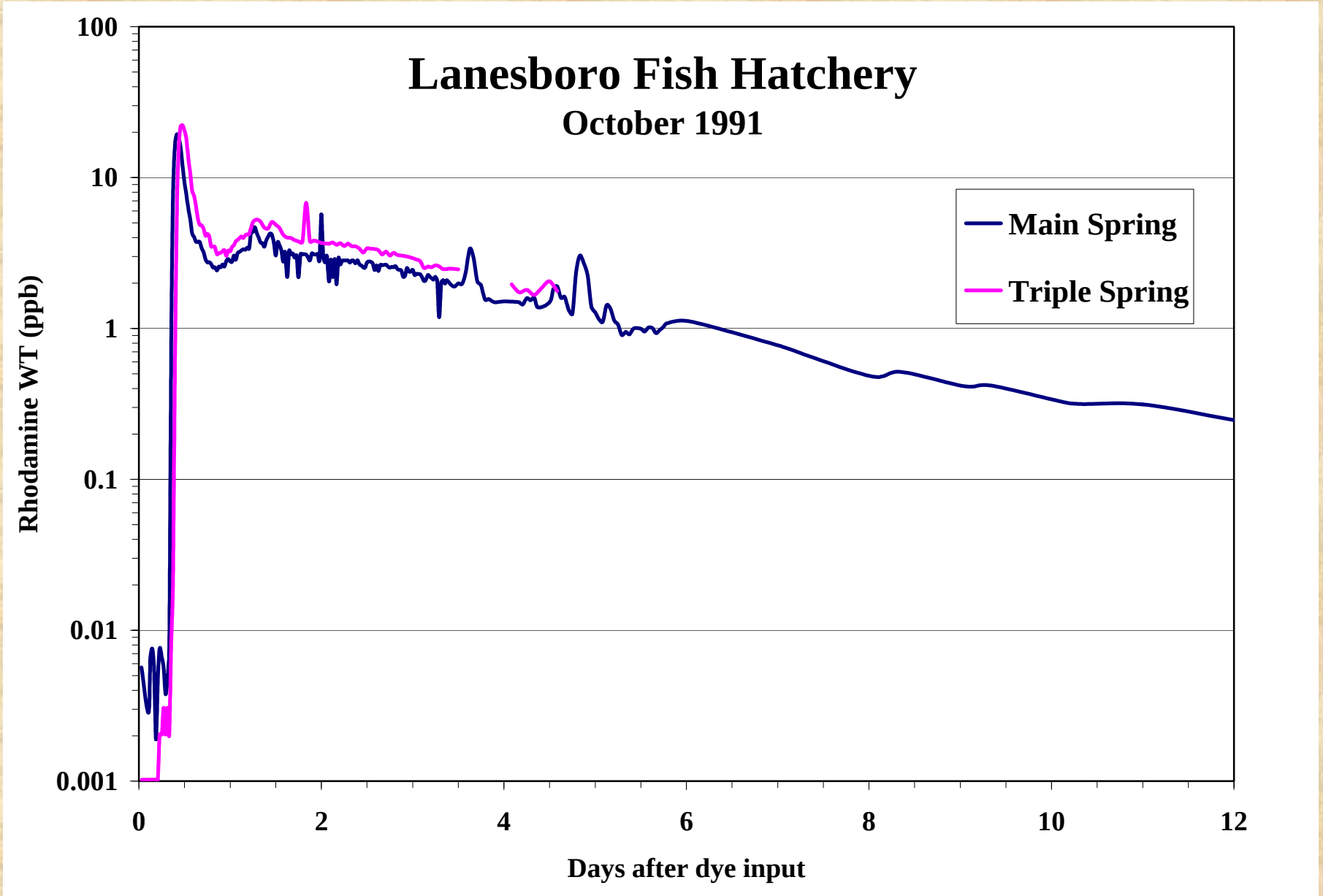

LANESBORO TRIPLE
Lanesboro Fish Hatchery June 1987
Rhodamine WT (ppb)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
20
40
60
80
100
120
Hours after dye input


STATION 8
Duschee Creek March 1987
Rhodamine WT (ppb)
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
Hours after dye input

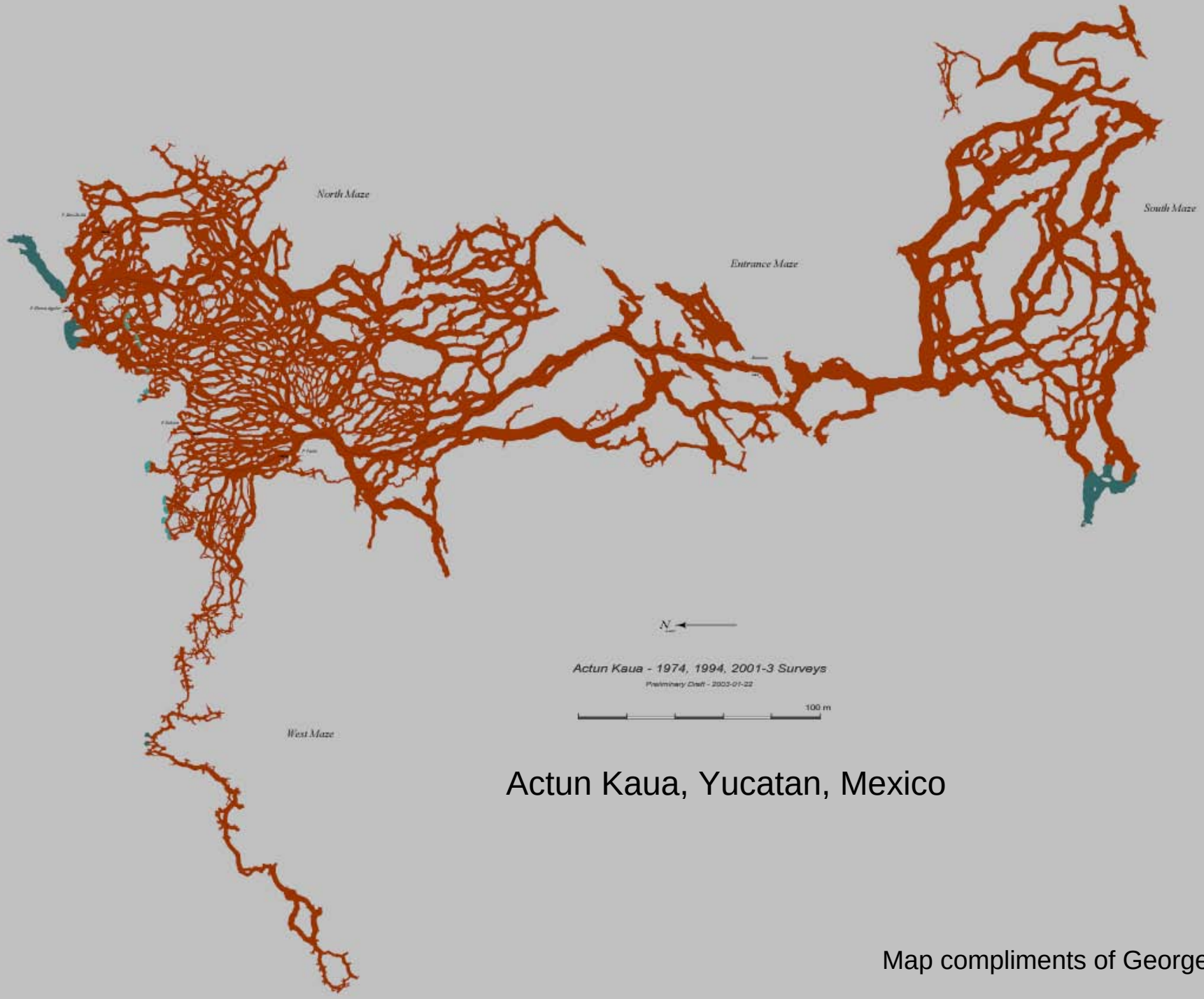

Triple Spring and Duschee Creek #8
Lanesboro Fish Hatchery
Rhodamine WT (ppb)
0
20
40
60
80
100
120
Hours after dye input


Lanesboro Fish Hatchery
October 1991
Rhodamine WT (ppb)
25
20
15
10
5
0
0
2
4
6
8
10
12
Days after dye input
Main Spring
Triple Spring


Lanesboro Fish Hatchery
October 1991
Main Spring
Triple Spring
Rhodamine WT (ppb)
100
10
1
0.1
0.01
0.001
0
2
4
6
8
10
12
Days after dye input

Anastamoses on ceiling of Diamond Caverns, KY


Expedia
Tucson
NEW MEXICO
El Paso
Abilene
Dallas
ARKANSAS
Monroe
Montgomery
Natchitoches
Jackson
ALABAMA
Waco
GREAT PLAINS
UNITED STATES
LA
Baton Rouge
Mobile
Nogales
Cananea
Nuevo Casas Grandes
SONORA
Austin
Lafayette
New Orleans
Hermosillo
CHIHUAHUA
San Antonio
Houston
Guaymas
Ciudad Obregón
Chihuahua
Piedras Negras
TEXAS
Camargo
Monclova
Laredo
Corpus Christi
Los Mochis
Reynosa
Matamoros
Torreón
Guamúchil
DURANGO
Saltillo
Monterrey
Culiacán
La Paz
Durango
Gulf of Mexico
Tropic of Cancer
Victoria
Mérida
Poza Rica
Jalapa
Campeche
Veracruz
Villahermosa
Chetumal
OAXACA
BELIZE
La Ceiba
Tuxtla Gutiérrez
GUATEMALA
Tegucigalpa
Quetzaltenango
EL SALVADOR
León
KAUA
LEGEND
Ruins
Río Lagartos
El Cuyo
Holbox
Isla Holbox
Isla Contoy Bird Sanctuary
SAN FELIPE NATURE RESERVE
RÍO LAGARTOS NATURE RESERVE
Chiquilá
Telchac Puerto
Progreso
Yucalpetén
Sisal
Punta Sam
Isla Mujeres
Puerto Juárez
Cancún
Motul
Tizimín
Kantunil Kin
CELESTÚN NATURE RESERVE
Dzibilchaltún
Mérida
Izamal
Itzamná
Ekbalám
Nuevo Xcan
Celestún
Uman
Kanacin
Acanceh
Balancanché Caves
Puerto Morelos
Telchquillo
Chemax
Oxkintoc
Mayapán
Chichén-Itzá
Valladolid
Puerto Calica
Punta Bete
Playa del Carmen
Halacho
Muna
Yaxuná
Puerto Aventuras
Xcaret
Xpu-Ha
Pamul
Isla de Cozumel
Beca
Uxmal
Ticul
Cobá
Calkiní
Kabah
Loltún Cave
Oxkutzcab
YUCATÁN
Akumal
Xel-Há
Labná
Sayil
Xlapak
Tulúm
XEL-HA LAGOON NATIONAL PARK
I. Jaina
Tekax
San José
Tenabó
Chunyaxche
Chacmultún
Melchor Ocampo
Chumpón
Muyil
Boca Paila
Campeche
Hopelchen
Vigía Chico
Punta Allen
Bahía de la Ascensión
Edzná
Champotón
Felipe Carrillo Puerto
QUINTANA ROO
SIAN KA'AN BIOSPHERE RESERVE
Bahía del Espíritu Santo
CAMPECHE
To CD del Carmen
Valle Hermoso
0 50 mi
0 50 km
95°
90°
15°
20°
25°
30°



Actun Kaua, Yucatan, Mexico

Map compliments of George Veni

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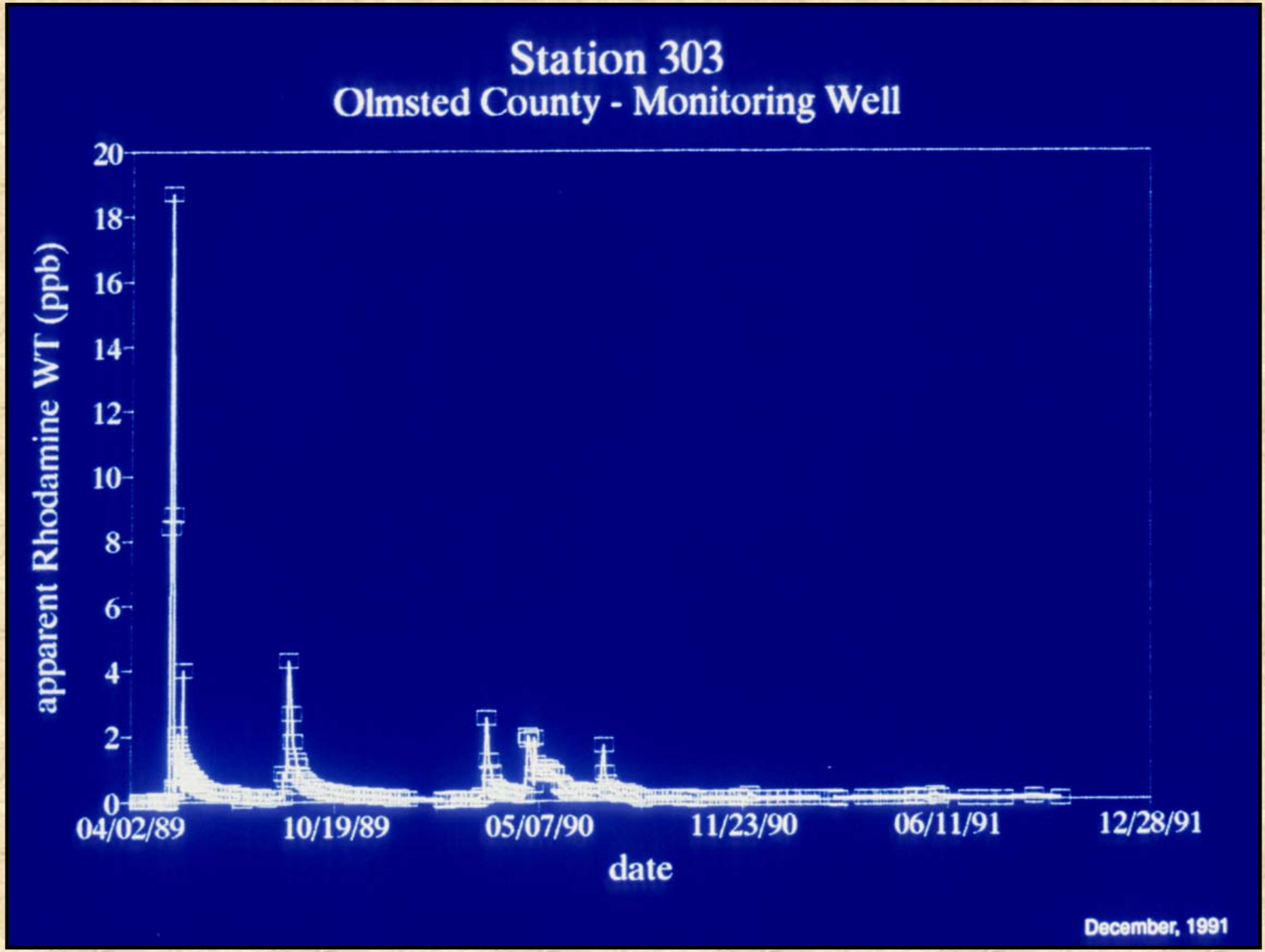
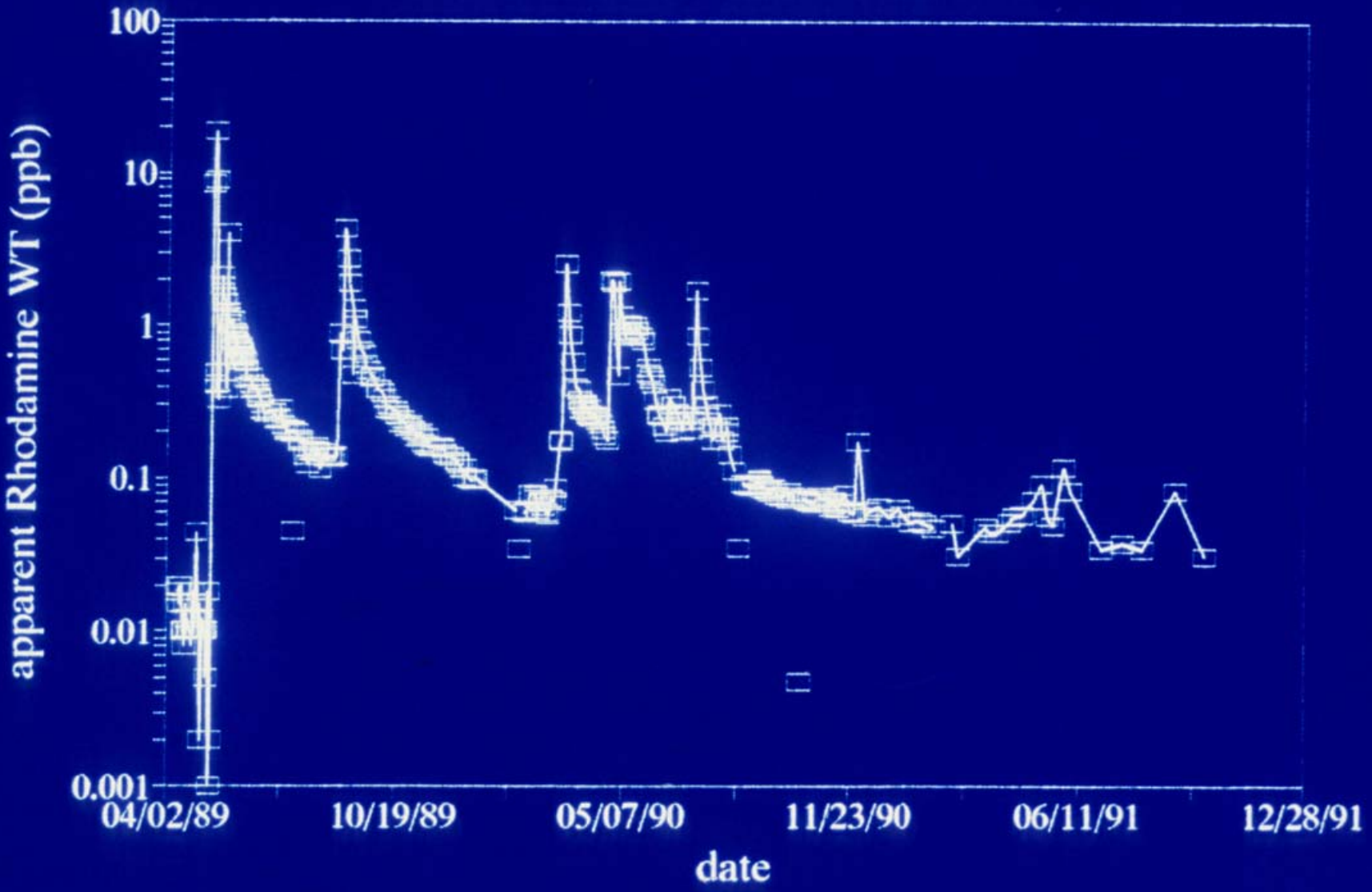
Oronoco Landfill Dye Trace, Olmsted County 1989


Station 303
Olmsted County - Monitoring Well
apparent Rhodamine WT (ppb)
20
18
16
14
12
10
8
6
4
2
0
04/02/89
10/19/89
05/07/90
11/23/90
06/11/91
12/28/91
date
December, 1991

Station 303
Olmsted County - Monitoring Well



December, 1991

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Summary

1. **Dendritic Conduit Flow**
   a) **Normal Flow – single, narrow, asymmetric breakthrough curves – velocities of km/day.**
   b) **High Flow – two, overlapping breakthrough curves – velocities of km/day.**
2. **Anastomosing, High Transmissivity Zones**

   Complex, multi-peaked, broad breakthrough curves – leading edge velocities of km/day.
3. **Vadose Zone Flow**

   Multiple breakthrough curves driven by recharge events – can continue for several years.
4. **Mixed Flow Systems.**