HISTORICAL PERSPECTIVE OF THE U.S. DEPARTMENT OF INTERIOR NATIONAL IRRIGATION WATER QUALITY PROGRAM

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ABSTRACT: In 1982, deformaties, reproductive failures, and mortalities among waterfowl and shorebirds were discovered at Kesterson National Wildlife Refuge in the San Joaquin Valley of California. Studies during 1982-85 determined the cause to be elevated levels of selenium in irrigation drainwater discharged to the refuge. The U.S. Department of the Interior then embarked on a program to determine whether other Department constructed or managed irrigation projects, national wildlife refuges, or other wetland areas in the Western United States for which the Department of the Interior has responsibilities under the Migratory Bird Treaty Act or other legislation might be experiencing similar or other irrigation-related problems.

As the program evolved, it became a five-phase process: (1) Site Identification, (2) Reconnaissance Investigations, (3) Detailed Studies, (4) Planning, and (5) Remediation.

In studies completed in 25 areas, selenium is the trace element found most often at elevated concentrations in water, bottom sediment, and biota. Boron, arsenic, mercury, and pesticide residues have also been found at elevated levels in some areas. Bioaccumulation of constituents associated with irrigation drainage is common.
KEY TERMS: irrigation drainage; water quality; selenium.

INTRODUCTION

During the last decade, there has been increased concern about the quality of irrigation drainage and its potential harmful effects on human health, fish, and wildlife. Concentrations of selenium greater than the 5 micrograms per liter (µg/L) water-quality criteria for the protection of aquatic life (U.S. Environmental Protection Agency, 1987) have been detected in surface and subsurface drainage from irrigated land. In 1982, incidences of mortality, birth defects, and reproductive failures in waterfowl were discovered by the U.S. Fish and Wildlife Service at the Kesterson National Wildlife Refuge in the western San Joaquin Valley of California where irrigation drainwater was impounded. In studies during 1982-85, the link was made between elevated concentrations of selenium in irrigation drainwater and contaminated wildlife (Presser and Ohlendorf, 1987; Ohlendorf, 1989).

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irrigation water applied to soils on the western side of the San Joaquin Valley mobilized selenium that was transported by tile drains to a canal and impounded in Kesterson Reservoir to augment water supplies for the refuge. The reservoir, closed in 1988, was an artificial wetland with no external drainage.

Widespread concern among the media, environmental organizations, the public, and the Congress over the effects of toxicity associated with irrigation drainage prompted the Secretary of the Interior in 1985 to investigate whether problems related to selenium or other trace inorganic or organic constituents in irrigation drainage might not be limited to Kesterson Reservoir. Several television programs, more than 100 newspaper and magazine articles, one Congressional hearing, and numerous organizational inquiries focused on these problems. In December 1985, the U.S. Department of the Interior (DOI) presented a program entitled "Department of the Interior Management Strategy for Irrigation-Induced Water Quality Problems" to the Congress.

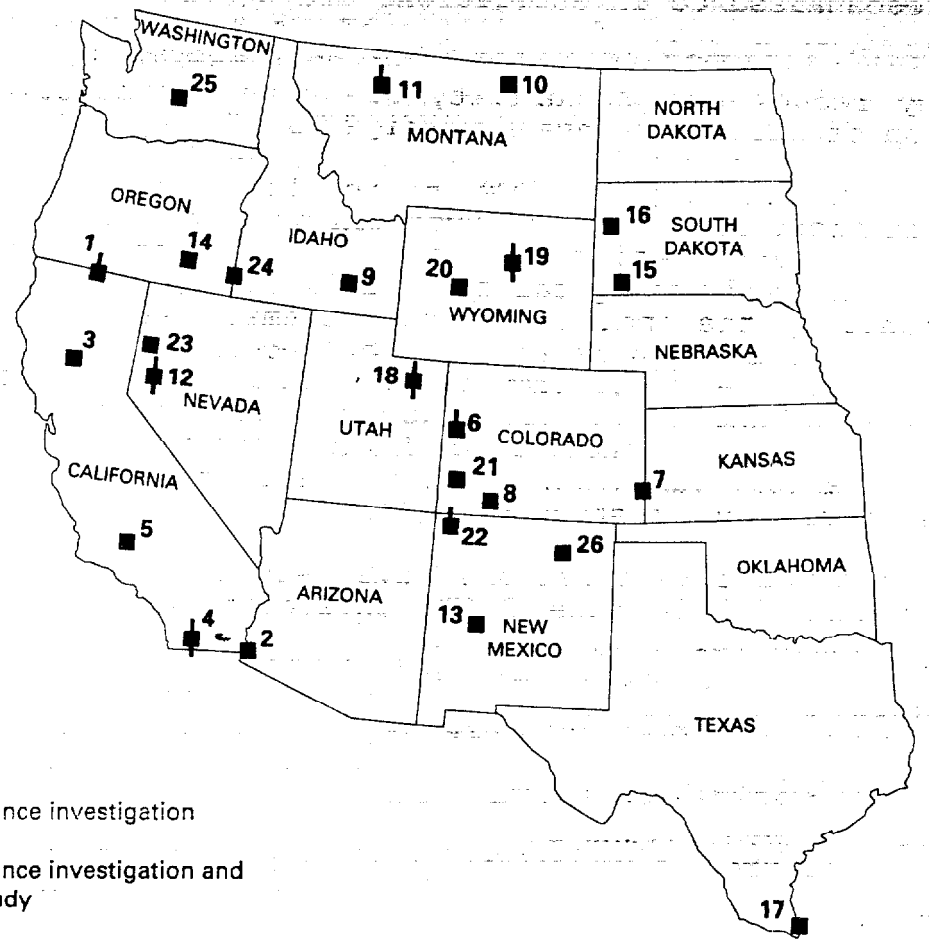
The purpose of this paper is to describe the results of 25 studies completed in 14 Western States to determine whether problems or potential problems are associated with drainwater from DOI irrigation projects.

PROGRAM STRUCTURE

To implement study of irrigation-induced problems, the DOI began the National Irrigation Drainage Program, subsequently renamed the National Irrigation Water Quality Program (NIWQP), to determine whether irrigation-related problems existed at other DOI constructed or managed irrigation projects, national wildlife refuges, or other wetland areas for which the DOI has responsibilities under the Migratory Bird Treaty Act, the Endangered Species Act, or other legislation. As the program evolved, it has become a five-phase process (Deason, 1986): (1) site identification, (2) reconnaissance investigations, (3) detailed studies, (4) planning, and (5) remediation. Activities in the first three phases are conducted by study teams composed of scientists from the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (FWS), the Bureau of Reclamation (BOR), and the Bureau of Indian Affairs (BIA). A USGS scientist heads each study team for reconnaissance investigations and detailed studies. Activities for phases 4 and 5 are under the leadership of the BOR.

Site Identification

Historically, approximately 600 irrigation projects and major wildlife resource areas have been constructed or are managed in 17 Western States by DOI Bureaus. A comprehensive survey identified 31 projects or areas in 15 states as potential problem areas. Twenty of these areas in 13 states were recommended by DOI bureaus in 1985 for reconnaissance-level investigations. By 1992, additional study areas were identified bringing the total to 26. The location and activity status of each of these areas is shown on Figure 1.



EXPLANATION

- Reconnaissance investigation
- Reconnaissance investigation and detailed study
- Reconnaissance investigation, detailed study, and planning for remediation

STUDY AREA

1. Klamath Basin Refuge Complex, CA-OR
2. Lower Colorado River Valley, CA-AZ
3. Sacramento Refuge Complex, CA
4. Salton Sea Area, CA
5. Tulare Lake Bed Area, CA
6. Gunnison River Basin/Grand Valley Project, CO
7. Middle Arkansas River Basin, CO-KS
8. Pine River Area, CO
9. American Falls Reservoir, ID
10. Milk River Basin, MT
11. Sun River Area, MT
12. Stillwater Wildlife Management Area, NV
13. Middle Rio Grande and Bosque del Apache National Wildlife Refuge, NM
14. Malheur National Wildlife Refuge, OR
15. Angostura Reclamation Unit, SD
16. Belle Fourche Reclamation Project, SD
17. Lower Rio Grande and Laguna Atascosa National Wildlife Refuge, TX
18. Middle Green River Basin, UT
19. Kendrick Reclamation Project Area, WY
20. Riverton Reclamation Project, WY
21. Dolores-Ute Mountain Area, CO
22. San Juan River Area, NM
23. Humboldt River Area, NV
24. Owyhee-Vale Reclamation Project Areas, OR-ID
25. Columbia River Basin, WA
26. Vermejo Project, NM

FIGURE 1. LOCATION OF STUDY AREAS, NATIONAL IRRIGATION WATER QUALITY PROGRAM, 1986-1994

Reconnaissance Investigations

Reconnaissance investigations are designed to determine whether (1) irrigation drainage has caused or has the potential to cause significant harmful effects on human health or on fish and wildlife, or (2) may reduce the suitability of water for beneficial uses. The duration of reconnaissance investigations is approximately 2 years.

To enhance comparability of results among the study areas, the investigations are guided by a common protocol developed by the NIWQP. However, study designs differ because of unique hydrologic, geochemical, and ecological systems in each area. Sampling sites are determined by the individual study teams. Samples of water, bottom sediment, and biota generally are collected before, during, and after the irrigation season. Samples of each medium are analyzed for major constituents and trace elements including arsenic, barium, boron, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, and zinc. Pesticide analyses are performed at the discretion of study teams.

Reconnaissance investigations have been completed for 25 of the 31 areas identified in Phase 1. An investigation in one area is ongoing and scheduled for completion in late 1994. A reevaluation of data assembled during Site Identification (Phase 1), and subsequent available data (1993), did not indicate a need for study in the remaining five areas. However, four areas that were not part of the original 31 were selected for field screening studies on the basis of new data. Field screening is limited to one-time sampling and analysis of water, sediment, and biota to determine whether there is a problem or potential problem associated with irrigation drainage. Reports are published for 22 areas. Each report contains a complete tabulation of the data collected and a discussion of those data.

Detailed Studies

Detailed studies are initiated if reconnaissance investigations indicate that potentially serious water-quality problems are related to irrigation drainage. The purpose of detailed studies is to gather sufficient information to provide the scientific understanding needed for development of reasonable alternatives to mitigate or resolve identified problems. Whereas reconnaissance investigations are designed to study the location and amounts of potentially toxic constituents, detailed studies are process-oriented and tailored specifically to each individual area. The studies include source identification, transport mechanisms, fate of potentially toxic constituents, bioaccumulation, and quantification of adverse effects. Detailed studies are usually of 3-year duration.

Of the 9 areas for which reconnaissance investigations were completed prior to 1989, five were determined to have problems that warranted further study. One area was incorporated into an ongoing study outside the NIWQP. Detailed studies were completed in four areas by the end of 1990, and were started in four other areas during 1990-1993. Seven studies have been completed and one is ongoing. Physical, chemical, and biological data and interpretive reports for four areas are published.

Planning

The purpose of the planning phase is to develop coordinated action for cleanup with appropriate Federal, State, and local agencies. When a reconnaissance investigation indicates that potentially serious problems exist and that detailed study is needed, it generally but not necessarily implies that the final two phases of the program will be required at the site. Three-year planning studies began in 1991 for four areas. Results from studies just completed are currently being evaluated for the need to plan for remediation.

Remediation

The final phase, remediation, involves implementation of corrective actions developed during the planning process. Although not part of the NIWQP, some remediation has been implemented at Kesterson Reservoir. No areas are currently in remediation under the NIWQP.

Data Synthesis

In the early stages of planning the NIWQP, a collective evaluation of all data for all studies was identified as an essential element of the Program. In 1992, a Data Synthesis Team was formed to conduct the evaluation. The initial activity has been creation of a relational data base of the more than 10,000 chemical analyses of water, sediment, soil, and biological samples collected throughout the 25 study areas. The data base is complete and includes physical data that describe the study areas and sampling sites (Seiler, 1994). Evaluation of the data is in progress using a multidisciplinary approach to identify commonalities that bear upon irrigation-induced water-quality problems, both known and potential. The synthesis is scheduled for completion in 1995.

SELENIUM CONCENTRATIONS IN ALL MEDIA

Selenium is the trace element found most frequently at elevated concentrations in all sampled media in the 25 reconnaissance study areas for which studies are complete. Elevated selenium concentrations are most frequently observed in areas where a geologic source of selenium is present. Selenium is readily mobilized from oxidized-alkaline soils derived from seleniferous marine shales of Cretaceous age by the application of irrigation water (Sylvester and others, 1988; Feltz and others, 1990). If the area also is characterized by low rainfall, high evaporation, and lacks external drainage, the chances of elevated selenium concentrations are enhanced. Even under these conditions, contamination problems are mostly site specific within the study areas. Boron, arsenic, and pesticide residues were also found at elevated levels in some areas. Because of space limitations, and high incidence of selenium contamination, the following discussion deals only with that chemical element.

Selenium concentrations in samples of water, bottom sediment, whole body fish and bird livers from 25 reconnaissance study areas are shown in Table 1. The areas numbered 1-25 are keyed to the numbers on Figure 1. Some data from detailed studies are included for those areas in Table 1 marked with an asterisk.

TABLE 1. Selenium concentrations in samples of water, bottom sediment, whole body fish and bird livers from 25 reconnaissance study areas, Western United States 1986-1993
[Abbreviations: µg/L, micrograms per liter; µg/g, micrograms per gram. Reporting limits: Water 1 µg/L; bottom sediment, whole body fish and bird livers 0.1 µg/g dry weight; all analyses by USGS and FWS laboratories; areas are keyed by number to Figure 1; * includes data from detailed study]

Study Area	Number of Samples	Range	Median	Number of Samples	Range	Median
	Water (µg/L)			Bottom Sediment (µg/g dry weight)		
1	16	<1-<1	<1	11	0.1-0.7	0.5
2	14	<1-2	1	10	0.1-7.1	1.2
3	26	<1-5	<1	13	0.1-0.4	0.2
4	258*	1-360	44	17	<0.1-3.3	0.7
5	12	<1-390	35	9	<0.1-19	0.2
6	461*	<1-1300	11	18	1.5-47	6.0
7	26	1-52	6	13	0.5-5.4	1.3
8	68	<1-4800	2	10	0.2-0.8	0.5
9	19	<1-6	<1	9	0.1-1.9	0.5
10	16	<1-1	<1	6	0.3-0.6	0.4
11	27	<1-580	2	14	0.3-6.7	0.8
12	288*	<1-110	<1	35	<0.1-8.3	0.5
13	29	<1-1	<1	11	0.2-0.4	0.3
14	20	<1-<1	<1	5	0.1-0.6	0.3
15	32	<1-16	3	9	0.6-14	1.0
16	30	<1-11	2	8	0.6-2.8	0.9
17	15	<1-2	<1	15	0.3-0.7	0.4
18	446*	<1-16000	20	7	4.2-85	10
19	412*	<1-14000	7	28	0.5-43	3.0
20	26	<1-12	2	14	0.1-3.0	0.4
21	77	<1-88	<1	18	0.1-4.3	0.5
22	78	<1-67	<1	18	0.1-37	0.6
23	49	<1-4	<1	10	0.2-1.4	0.6
24	41	<1-5	<1	17	0.2-0.6	0.4
25	51	<1-4	<1	21	0.1-4.1	0.3
	Fish (µg/g dry weight whole body)			Bird Livers µg/g dry weight)		
1	19	0.43-1.2	0.70	15	2.8-16	4.2
2	31	2.4-16	6.1	0	-	-
3	27	0.50-2.0	1.4	52	1.5-11	3.7
4	25	3.5-20	7.7	23	6.7-42	19
5	33	0.60-4.3	1.5	10	26-120	>30
6	55	1.3-50	5.0	17	6.5-84	31
7	59	2.1-20	11	78	0.32-56	16
8	153	0.92-16	4.2	9	4.2-50	6.8
9	10	0.1-2.6	1.0	10	0.80-42	8.0
10	2	2.3-2.5	2.4	14	2.1-7.4	3.4
11	8	2.2-48	2.5	15	2.3-46	25
12	98	0.69-11	1.7	239	1.0-48	6.9
13	14	0.57-1.7	0.96	24	0.85-9.1	3.7
14	11	0.66-3.1	2.0	15	3.9-36	14
15	126	2.1-13	4.4	0	-	-
16	128	1.4-5.3	2.8	8	6.5-28	12
17	22	0.59-3.4	1.7	0	-	-
18	10	3.1-31	20	17	2.0-43	7.1
19	11	1.9-49	6.1	12	13-170	30
20	69	0.48-15	5.9	32	1.3-35	9.0
21	179	0.49-26	2.0	9	1.8-38	4.7
22	48	0.3-42	2.4	50	2.7-103	14
23	42	0.1-4.9	2.4	53	7.0-48	12
24	45	0.82-4.7	1.7	10	2.6-18	11
25	73	0.68-3.6	1.4	23	0.94-4.2	2.9

Water analyses are from all sources within each reconnaissance area including background or reference areas, canals, lakes or ponds, ground water, surface drains, receiving streams, and wetlands. The maximum observed selenium concentration of 16,000 µg/L was in a ground water sample from the Middle Green River Basin, Utah. The largest median concentration was 44 µg/L in the Salton Sea area of California. The median selenium concentration was below the reporting limit of 1 µg/L at 13 sites and was 2 µg/L or below at 5 additional sites. Very large concentrations (>500 µg/L) were observed exclusively in ground water samples or saline seeps in five areas. Minimum concentrations were at or below the reporting limit for all areas, even in areas where very large concentrations were observed in ground water. This demonstrates the widely variable occurrence of selenium, including those areas where selenium sources are found. Most water samples were collected in the spring before delivery of irrigation water; in the summer at the height of irrigation season and at the time of nesting for waterbirds; and in late fall after the irrigation season. Generally, the largest selenium concentrations were observed prior to the irrigation season when the previous year's "residue" is washed from the irrigated areas and drains, and before dilution by irrigation water.

Bottom sediment samples were collected once each year during low-flow conditions from streams, drains, lakes, and wetlands. Generally, but not always, bottom sediment sampling coincided with the water samples collected in late fall. The maximum observed concentration of selenium in bottom sediment was 85 micrograms per gram (µg/g) dry weight from a drain to Stewart Lake in the Middle Green River Basin, Utah. The largest median concentration was 10 µg/g also from the Middle Green River Basin. The smallest median concentration was 0.2 µg/g from the Sacramento Refuge Complex, California. Median concentrations were below 1.0 µg/g in 19 of 25 areas, indicating that even though selenium concentrations in bottom sediment are elevated at some locations, selenium in bottom sediment is of little concern in most of the 25 reconnaissance areas.

Fish were collected at all sites in upstream areas, drains, receiving streams, lakes, and reservoirs. Data for all species of fish are grouped in Table 1. The same species of fish were not always available at each site but carp and suckers were found at most sites. The maximum observed selenium concentration was 50 µg/g dry weight in a fish from the Gunnison River Basin/Grand Valley Project in Colorado. The largest median concentration in fish was 20 µg/g dry weight from the Middle Green River Basin, Utah. The smallest median selenium concentration was 0.70 µg/g dry weight from the Klamath Basin Refuge Complex, California-Oregon. Median concentrations were below 3.0 µg/g in 16 areas and exceeded 10 µg/g in two areas. Dead or deformed fish related to selenium toxicosis were not reported for any reconnaissance area. Unhealthy fish with body lesions were observed in some areas, but there was no indication that selenium was the primary cause of these problems.

Adult and juvenile migratory birds were collected from 22 of the 25 reconnaissance areas, mostly from lakes, reservoirs, and wetlands. Sampling was done when birds were in residence during the nesting season (May-July), or in some cases, when adult birds were passing

through during annual migrations. All species of water birds are included in Table 1, but mallards were the most common species collected. The maximum observed selenium concentration in the livers of migratory birds was 170 µg/g dry weight from the Kendrick Reclamation Project Area, Wyoming. The largest median concentrations observed were 31 µg/g, >30 µg/g, and 30 µg/g (all dry weight) in the Gunnison River Basin/Grand Valley Project, Colorado, the Tulare Lake Bed Area, California, and the Kendrick Reclamation Project Area, Wyoming, respectively. Median concentrations were below 8.0 µg/g dry weight in 10 of the 22 areas. Deformed waterbird embryos presumably related to selenium contamination have been confirmed for the Kendrick Reclamation Project, Wyoming, the Middle Green River Basin, Utah, and Tulare Lake Bed Area, California.

Deformities observed in the Stillwater Wildlife Management Area in Nevada may not be related to selenium toxicosis, and reported deformities observed in the Sun River Area, Montana, appear to occur at only the expected rate of deformities in a normal population. Because mostly adult bird liver data are included in Table 1, it cannot be proven conclusively that all the selenium in each bird liver was acquired within the area in which the bird was collected. Nevertheless, large median concentrations of selenium in livers of birds generally are found in areas where elevated selenium concentrations also occur in water, bottom sediment, and whole body fish. This relation indicates that, in all probability, most selenium was acquired within those areas.

Bioaccumulation of selenium in higher trophic levels of the food chain is evident at nearly every reconnaissance investigation location even though concentrations of selenium in whole body fish and in bird livers are well below thresholds of concern at several locations. Based on the data in Table 1, those areas where bioaccumulation of selenium may occur at concentrations of concern include the Salton Sea Area, California; the Tulare Lake Bed Area, California; the Gunnison River Basin/Grand Valley Project, Colorado; Sun River Area, Montana; Middle Green River Basin, Utah; Kendrick Reclamation Project Area, Wyoming; and the San Juan River Basin, New Mexico.

SUMMARY

Following the discovery of deformities, reproductive failures, and mortalities among waterfowl and shorebirds at the Kesterson National Wildlife Refuge in California, the U.S. Department of the Interior implemented the National Irrigation Water Quality Program in 1985 to determine whether other Department constructed or managed irrigation projects, national wildlife refuges, or other wetland areas in the Western United States for which the DOI has responsibilities might be experiencing similar or other irrigation-related problems.

As the NIWQP evolved, it became a five-phase process: (1) Site Identification, (2) Reconnaissance Investigations, (3) Detailed Studies, (4) Planning, and (5) Remediation. A comprehensive survey of approximately 600 irrigation projects and wildlife resource areas was conducted as part of Phase 1, and identified 31 areas in 15 states as potential problem areas.

Results of reconnaissance investigations completed in 25 areas have shown that irrigation-induced water-quality problems are mostly site specific within the areas studied. The most prevalent problems are related to the element selenium, which is readily mobilized from oxidized-alkaline soils derived from seleniferous marine shales of Cretaceous age by the application of irrigation water. Areas with low rainfall, high evaporation rates, and no external drainage are vulnerable to water-quality problems.

The highest concentrations of selenium were found in ground water or saline seeps. Minimum concentrations were at or below the analytical reporting limit for selenium for all study areas, even where large concentrations were observed in ground water.

Median concentrations of selenium in bottom sediment were below 1.0 µg/g in 19 of 25 areas, indicating that the element is of little concern in bottom sediment in most of the 25 reconnaissance areas.

The maximum observed selenium concentration in fish was 50 µg/g dry weight; the largest median concentration from a study area was 20 µg/g dry weight; and the smallest median concentration was 0.70 µg/g dry weight. Dead or deformed fish related to selenium toxicosis were not reported for any reconnaissance area.

The maximum observed selenium concentration in migratory bird livers was 170 µg/g dry weight from the Kendrick Reclamation Project Area, Wyoming. The largest median concentrations 31 µg/g, >30 µg/g, and 30 µg/g dry weight were observed in the Gunnison River Basin/Grand Valley Project, Colorado, the Tulare Lake Bed Area, California, and the Kendrick Reclamation Project Area, Wyoming, respectively. Because analyses were performed on mostly adult bird livers, it cannot be substantiated that all the selenium in each bird liver was acquired within the area in which the bird was collected. However, the largest median concentrations of selenium in bird livers generally are found where elevated concentrations of selenium are found in water, bottom sediment, and whole body fish. This would indicate that most of the selenium was likely acquired within those areas.

Bioaccumulation of selenium is evident in the higher trophic levels of the food chain in nearly every reconnaissance area, even though selenium concentrations in whole body fish and bird livers are below reported thresholds of concern.

Several reconnaissance investigation areas were determined to have problems warranting additional study. Seven detailed studies have been completed and another is ongoing. An evaluation of reports for the study areas indicated that planning for remediation was needed, and 3-year studies were started for four areas in 1991. Results for studies just completed are currently being evaluated to determine whether remediation might be necessary. None of the areas have gone to remediation.

A Data Synthesis Team is evaluating data collected for all studies since inception of the Program in 1986, and several reports are being published.

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