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Memorandum

To: MIDS Work Group
From: Barr Engineering Company
Subject: Regional Hydrologic Metrics – Precipitation (Item 3, Work Order 1)
Date: December 27, 2010
Project: 23/62 1050 MIDS

Precipitation is a key factor in designing stormwater management facilities so that a developed site's hydrology will mimic's its natural hydrology. Annual precipitation amounts and the intensities of storm events (inches per hour) vary throughout the State of Minnesota. These factors must be considered when developing a single state-wide stormwater management standard. This memorandum provides background on the variability of precipitation in the form of rainfall and snowfall, evaporation, and transpiration throughout the State of Minnesota.

Normal Precipitation Patterns

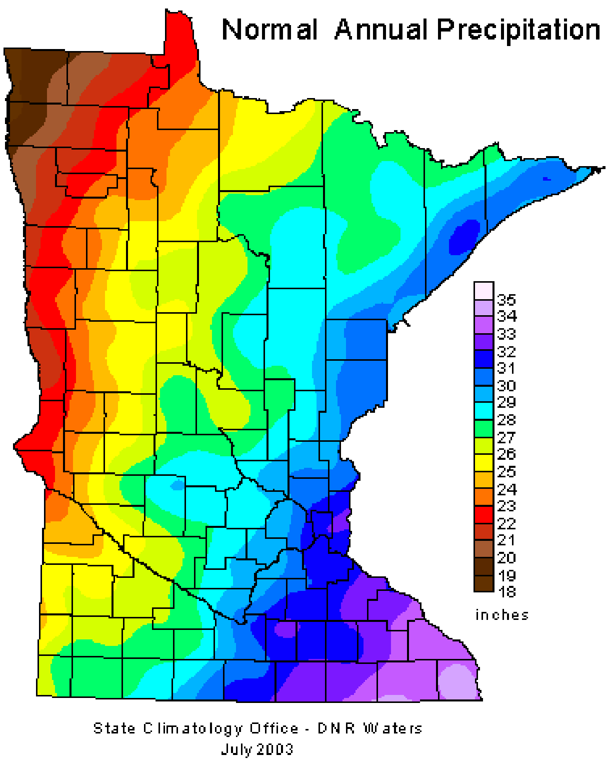

Figure 1. 1971-2000 Mean Precipitation Throughout Minnesota

Figure 1 shows the 1971-2000 arithmetic mean (climatologists call this 30-year arithmetric mean, which is updated once per decade, the "normal") annual precipitation throughout the State of Minnesota. A notable pattern of increasing precipitation from 18 inches per year in the far northwest corner of the state to 34 inches per year in the far southeast corner is shown.

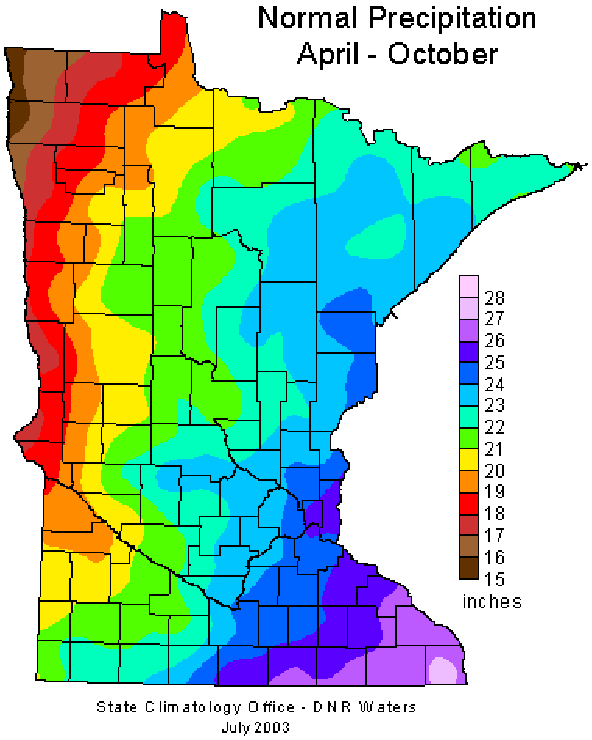

Figure 2. 1971-200 Mean April-October Precipitation Throughout Minnesota

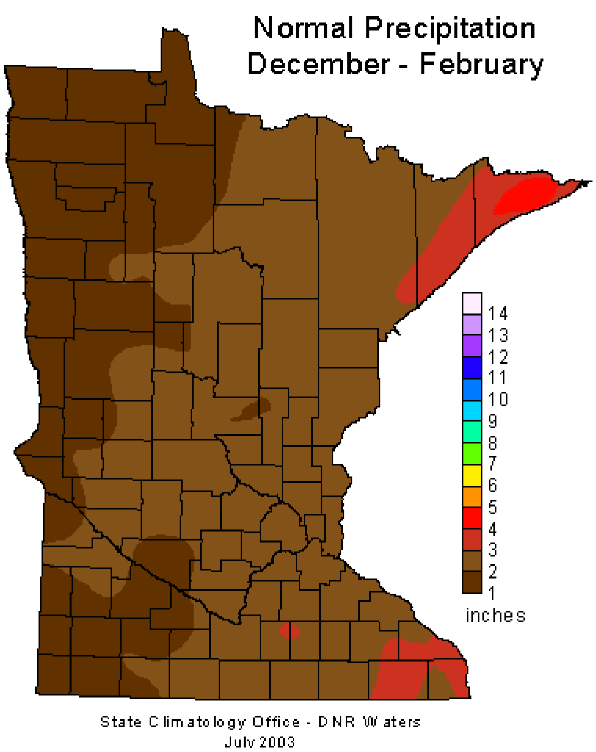

Figure 3. 1971-2000 Mean December - February Precipitation Throughout Minnesota

Figure 2 shows the 1971-2000 arithmetic mean precipitation patterns for the months of April through October, which is the growing season for native vegetation. Throughout the state, the "normal" precipitation ranges from 15 inches to 28 inches, with a pattern of increasing precipitation from the far northwest corner to the far southeast corner (similar to the normal annual precipitation).

Figure 3 shows the 1971-2000 arithemtic mean winter (December – February) precipitation throughout the state. For most of the state, the "normal" winter precipitation ranges between two and three inches, with the western portion of the state receiving less winter precipitation. A "normal" winter precipitation of three inches was observed in far southeast Minnesota and three to four inches in the far northeast due to lake effect.

Event-Based Rainfall

Water management features are commonly designed based on the anticipated amount of runoff from a rainfall event of a certain return frequency. For example, the widely-applied standard for design of flood control structures is the "100-year" storm event. Other storm water management structures may be designed for less frequent events; culverts under roadways are often designed to convey runoff from the 25- or 50-year storm event without runoff overtopping the road.

Although design storms are often referenced using terms like "100-year storm," a more appropriate way to characterize the storm is a "one percent probability of occurrence," indicating that the rainfall totals have a one percent probability of occurring at that location that year.

The duration of rainfall is an important consideration in hydrologic design. The storm duration that results in the highest peak rate and/or largest total volume is the "critical duration" storm. The critical duration is important to know when determining flood levels, sizing culverts, designing roads, etc. The critical duration will vary by watershed, depending on the size, drainage characteristics, and water management infrastructure. It is determined by comparing various durations of the specified storm frequency and calculating the peak rate and/or volume of runoff for each. For example, a 30-minute event might be the critical storm duration for sizing catch basin inlets and storm sewers from small watersheds. However, longer duration events such as the 3-hour, 12-hour, or 10-day runoff events might be the event durations that result in the most severe flood levels for lakes. Some regulators in Minnesota require that several storm durations be evaluated for determining the impacts from development projects. Many require the 24-hour design storm.

To accommodate the variation in critical storm duration, precipitation frequency analyses have been conducted and summarized for a range of rainfall durations. The commonly referenced Technical Paper 40 (TP 40) Rainfall Frequency Atlas of the United States (U.S. Weather Bureau, 1961), published by the National Weather Bureau, includes rainfall isopleths of varying frequency intervals for durations between 30-minutes and 24-hours (30-minutes, 1-, 2-, 3-, 6-, 12-, and 24-hour durations). An electronic copy of TP 40 is available at the following National Weather Service (NWS) website, which lists the most current NWS precipitation frequency documents and related studies for each state in the United States: http://www.weather.gov/oh/hdsc/currentpf.htm. Table 1 compares rainfall amounts in Minneapolis – St. Paul for two durations (30-minute and 24 hour) for several recurrence periods, based on TP 40.

Table 1. Comparison of rainfall amount for 30-minute and 24-hour duration events

Recurrence Period	30-minute Rainfall (inches)	24-hour Rainfall (inches)
1-year	0.9	2.3
2-year	1.1	2.8
5-year	1.45	3.5
10-year	1.65	4.1
25-year	1.9	4.8
50-year	2.1	5.3
100-year	2.4	5.9

Updates to the precipitation frequency and duration estimates for the Midwestern region are currently being prepared by the National Oceanic and Atmospheric Administration (NOAA). The project area includes Minnesota, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Colorado, Iowa, Missouri, Wisconsin, and Michigan. The NOAA is currently in the process of reviewing and reformatting precipitation data from numerous local, state, and federal sources. Precipitation frequency analysis is expected to occur in upcoming months, with draft results to be peer reviewed in the summer of 2011, and final results expected in the spring of 2012.

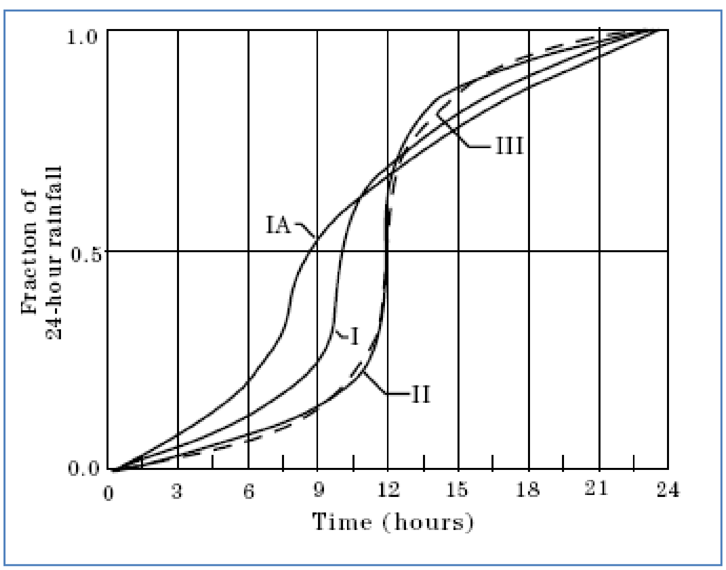

Figure 4. SCS 24-hour Rainfall Distributions (USDA, 1986)

A common practice in rainfall-runoff analysis is to utilize synthetic rainfall distributions in lieu of actual rainfall events. The Natural Resource Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS), developed four 24-hour synthetic rainfall distributions that represent the various geographic regions of the nation (Figure 4). As described in the HEC-HMS User's Manual, each distribution contains rainfall intensities arranged to maximize the peak runoff for a given total storm rainfall amount. The distribution is designed to 'nest' all storm durations (24 hours and less) and related peak intensities into a single 24-hour distribution that can be applied to watersheds of varying size. A storm period of 24 hours was chosen by the SCS for the synthetic distribution because, while longer than needed for determining peak runoff from most watersheds, the longer duration was appropriate for determining runoff volumes (USDA, 1986). The TP 40 24-hour duration rainfall isopleths for Minnesota for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year frequency rainfall are presented in Figures 5 through 11 on pages 8 through 14 of this memorandum, respectively.

Similar to "normal" annual precipitation, there is significant variation in 24-hour precipitation throughout the state. Table 2 summarizes the variability in 24-hour precipitation throughout the state for the 1-, 2-, 5-, 10-, 25-, 50-, and 100-year.

Table 2. Variability of 24-hour duration precipitation amounts throughout Minnesota

Recurrence Period	Range of Precipitation throughout Minnesota (inches)
1-year	1.8 – 2.6
2-year	2.1 – 2.9
5-year	2.8 – 3.7
10-year	3.3 – 4.4
25-year	3.9 – 5.0
50-year	4.4 – 5.6
100-year	4.8 – 6.2

90th Percentile Precipitation Frequency

In Issue Paper "B" of the MPCA's Minnesota Stormwater Manual (http://www.pca.state.mn.us/index.php/view-document.html?gid=8939), Emmons & Olivier Resources (EOR) and the Center for Watershed Protection (CWP) analyzed rainfall frequency to determine the 90th percentile rainfall depth. The 90th percentile rainfall depth represents the depth of rainfall in which 90% of the runoff-producing rainfall events were less than or equal to for the time period analyzed. For the

Minneapolis/St. Paul Airport precipitation station, EOR and CWP found that the 1.05 inch rainfall event corresponded to the magnitude of a single runoff-producing event that was equaled or exceeded in 90% of all events during the 1971-2000 time period. They further determined that 1.05 inches of rainfall represented 88% of the cumulative depth of rainfall over this period of record.

To evaluate the variation in rainfall depth throughout the state, EOR and CWP analyzed precipitation records from six stations in various Minnesota regions: Itasca, Cloquet, St. Cloud, Minneapolis/St. Paul, Lamberton, and Rochester. Table 3 summarizes EOR and CWP's analysis.

Table 3. Variability of 90th Percentile Precipitation (from EOR & CWP's Issue Paper "B" of the Minnesota Stormwater Manual)

Location	Region of State	Period of Record	90% Rainfall with Snow (inches)	90% Rainfall without Snow (inches)	95% Rainfall without Snow (inches)
Minneapolis/St. Paul Airport	East Central	1971-2000	0.98	1.05	1.49
St. Cloud Airport	Central	1971-2004	1.00	1.07	1.39
Rochester Airport	Southeast	1971-2000	1.01	1.12	1.55
Cloquet	Northeast	1971-2000	1.01	1.13	1.47
Itasca	Northwest	1971-2000	0.95	1.05	1.42
Lamberton	Southwest	1971-2000	1.03	1.09	1.48
Average			1.00	1.09	1.46
Variation			+/- 0.04	+/- 0.04	+/- 0.08

Climate Change

In March 2010, Barr Engineering Company (Barr) prepared a report, "Climate Change and Water Resources Management: A Literature Review for the Ramsey-Washington Metro Watershed District." The following sections briefly summarize how the predicted climate changes discussed in the report could affect stormwater management.

Temperature

As discussed in the Barr report to the Ramsey-Washington Metro Watershed District, many researchers have observed seasonal temperature variation trends. From a runoff perspective, this is important to keep in mind because if the projections are correct, Minnesota winters may be significantly different in the future, with fewer days where the temperature falls below freezing. By the end of the 21st century, these changes could result in a shortening of the frost season in the Midwest by moving the date of autumn frost 35 days later and the date of the last spring frost 15 to 35 days earlier (Wuebbles and Hayhoe, 2004).

Precipitation

Generally, precipitation in Minnesota has been rising (though not uniformly) since the dust bowl years of the 1930s. Research shows that the observed increase in annual precipitation in North America during the 20th century is due to an increased frequency of heavy to extreme precipitation events (Karl and Knight 1998). Groisman et al (2001) reported a 50% increase during the 20th century in the frequency of days with precipitation exceeding four inches in the upper Midwest. In response to the question, "Are larger precipitation events as portions of the total precipitation in a year changing?," the State Climatologist responded, "Yes, the amount of precipitation occurring as large events has been increasing for decades but about 100 years ago that fraction was similar to or even higher than what it is today."

Increases in the intensity and/or frequency of extreme flood-producing precipitation events is a plausible, though not certain, outcome of global warming. The most recent assessment of the Intergovernmental Panel on Climate Change (IPCC) asserts that increases in North American extreme precipitation events are highly likely in the future as a result of climate forcing by increasing greenhouse gas concentrations (Kunkel, 2003).

Changes to annual average precipitation in the Midwest could be as minor as 0 to 10% (Christiansen et al 2007), but many model projections indicate that there will be a shift in the seasonal distribution of the precipitation. Average winter precipitation across the region is likely to increase (up by 30% at the end of the century), while summer precipitation will likely remain the same or increase (Wuebbles and Hayhoe, 2004). Coupled with model projections of little net change in annual average precipitation but increased occurrence of precipitation intensity, this indicates that although rain may fall in more intense events, it may also fall less frequently, leaving drier periods between events and possibly increasing the risk of drought as well (Wuebbles and Hayhoe, 2004).

From a stormwater management perspective, if these predicted changes in precipitation occur, water quality treatment and flood protection Best Management Practices (BMPs) may need to be sized larger to capture and treat the runoff from the predicted more intense events. In addition, the predicted longer dry periods between precipitation events may result in greater stress to the vegetation in vegetated BMPs.

Evaporation and Evapotranspiration

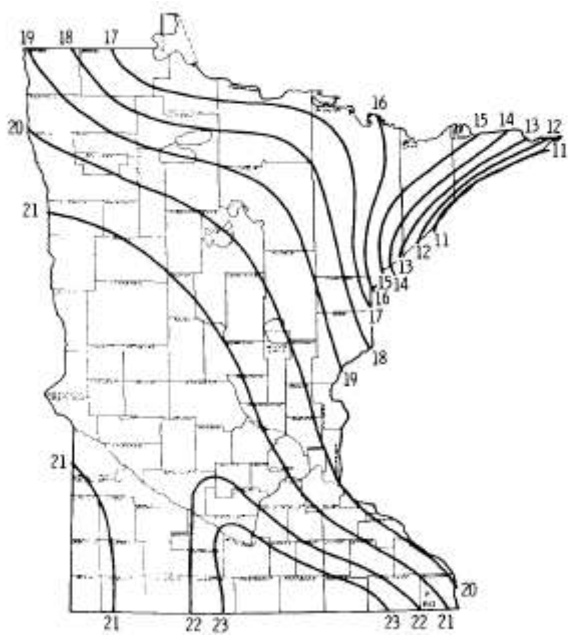

Figure 12. Estimated Mean Evapotranspiration (in inches) throughout Minnesota

Precipitation falling to the ground surface generally either runs off the land to nearby surface waters or is stored in the soil. A significant portion of the water stored in the soil will return to the atmosphere as vapor through evapotranspiration[1] (when plants are present) or evaporation[2], with the remaining infiltrating through the soil profile and replenishing groundwater supplies. The average water budget in Minnesota was approximated in a 1979 study, in which it was estimated that 76% of the annual precipitation is returned to the atmosphere through evapotranspiration, with 24% running off to surface water and infiltrating to groundwater (Baker, et al, 1979). Evapotranspiration is difficult to directly and accurately measure, and is most often estimated using a water balance approach. Mean evapotranspiration estimates made based on the difference between precipitation and runoff indicate that annual evapotranspiration varies significantly throughout the state, with the greatest rates in the southern part of Minnesota (Baker, et al, 1979) (Figure 12).

Evapotranspiration can also be approximated based on evaporation of water from pans. Average annual Class A pan evaporation throughout the state, shown in Figure 13, increases in a general pattern from the northeast corner of the state toward the southwest corner (U.S. Weather Bureau T.P. 37).

[1] Evapotranspiration is the process by which plants remove soil moisture through roots and release it back to the atmosphere.
[2] Evaporation is the when solar energy vaporizes water from water bodies, soil, and other source of water.

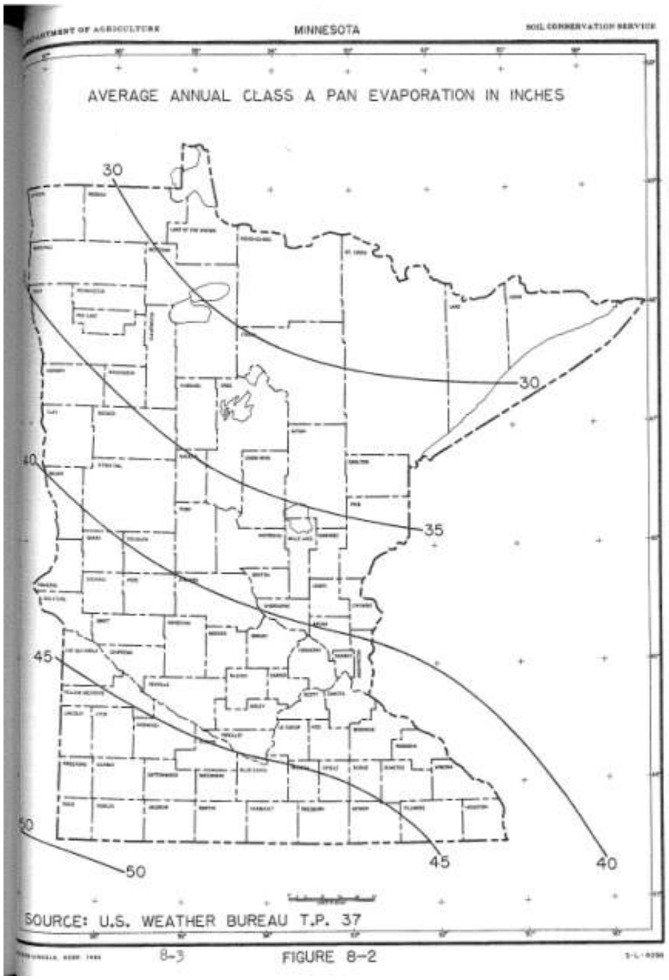

Figure 13 Average Annual Class A Pan Evaporation Throughout Minnesota

Application of Precipition to MIDS

Precipitation patterns vary through the state and need to be considered in developing a state-wide stormwater management standard. If climate change predictions come true, stormwater management practices may need to be sized larger to provide equivalent levels of water quality treatment and flood protection.

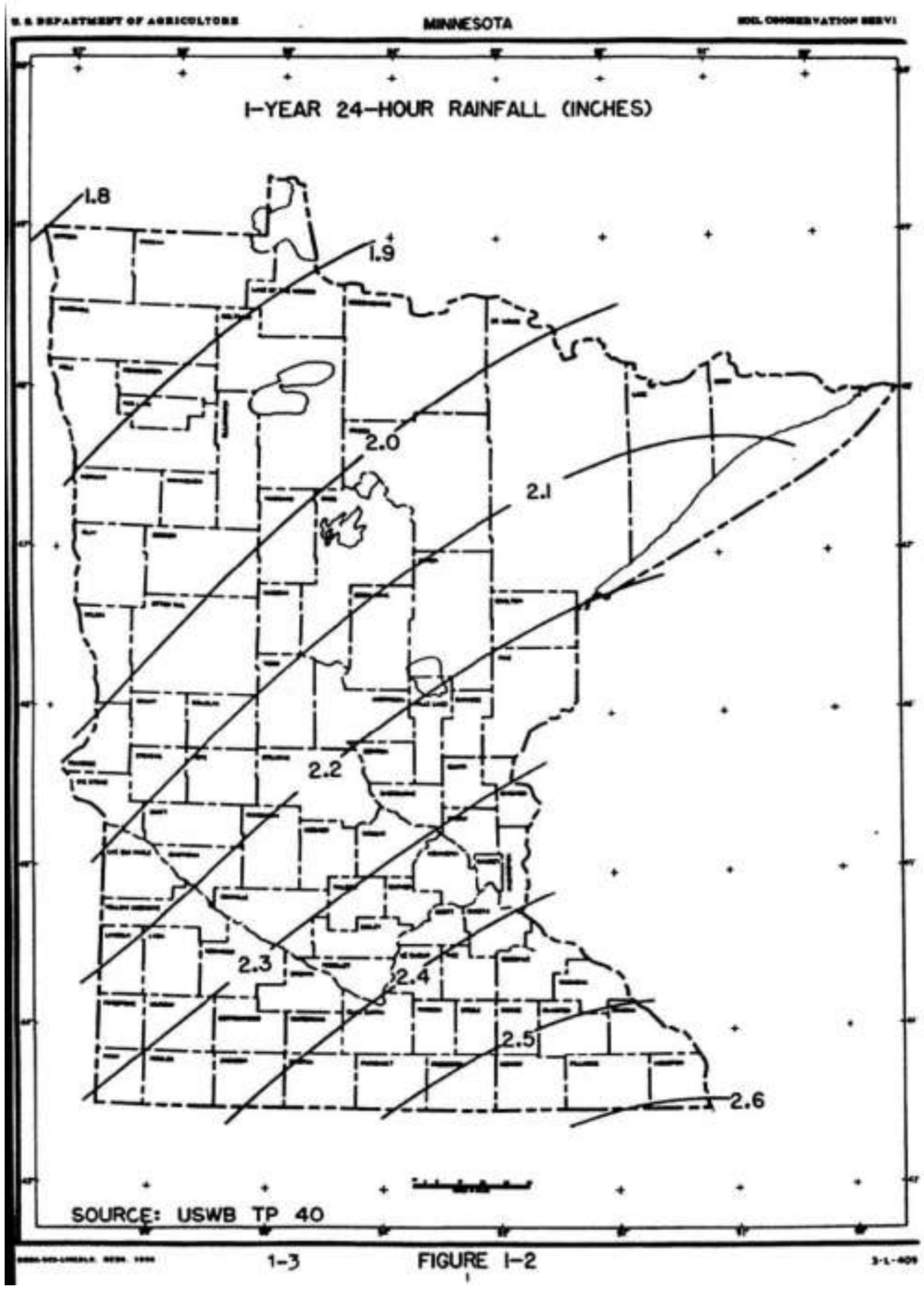

Figure 5. 1-Year 24-Hour Rainfall Throughout Minnesota

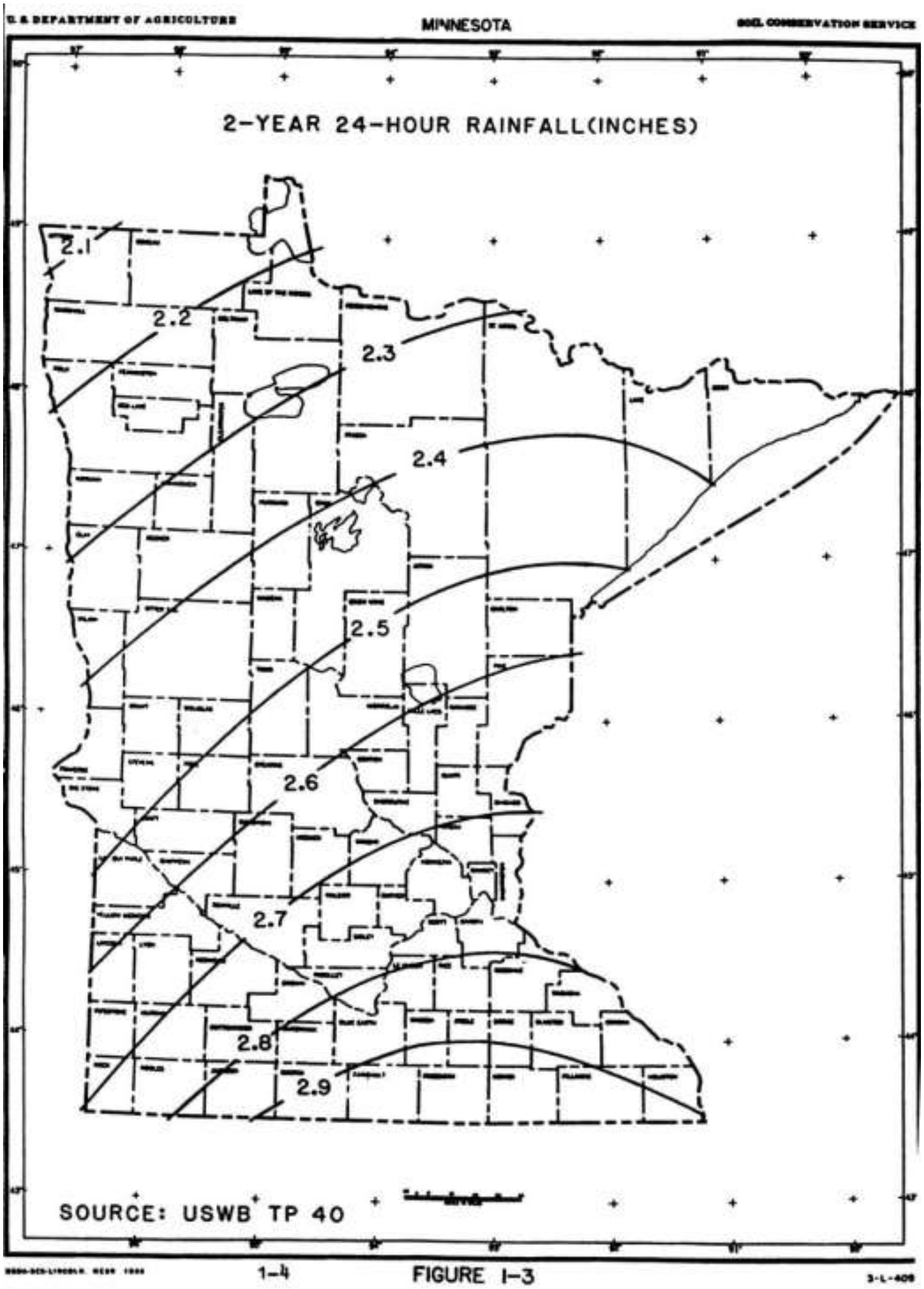

Figure 6. 2-Year 24-Hour Rainfall Throughout Minnesota

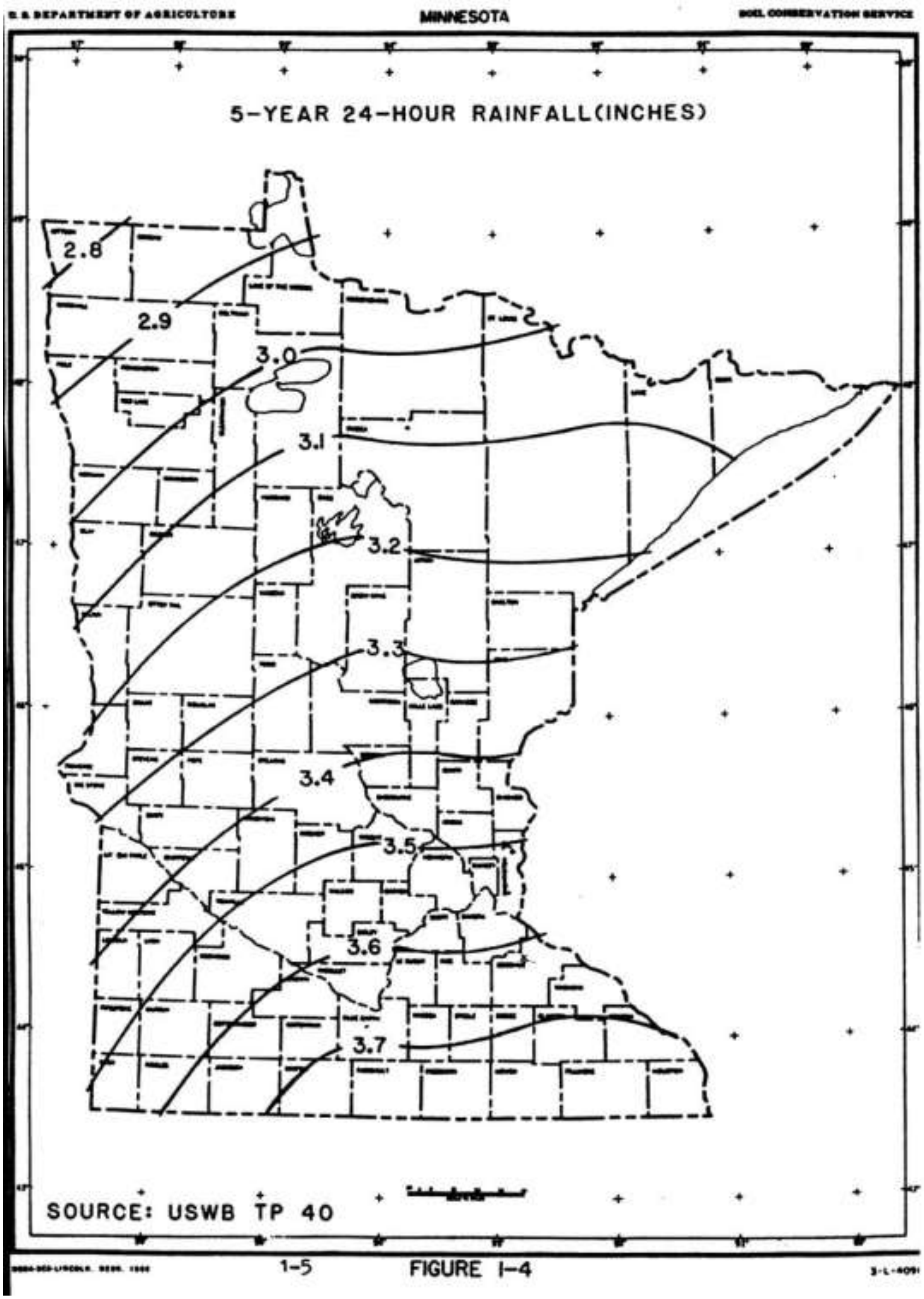

Figure 7. 5-Year 24-Hour Rainfall Throughout Minnesota

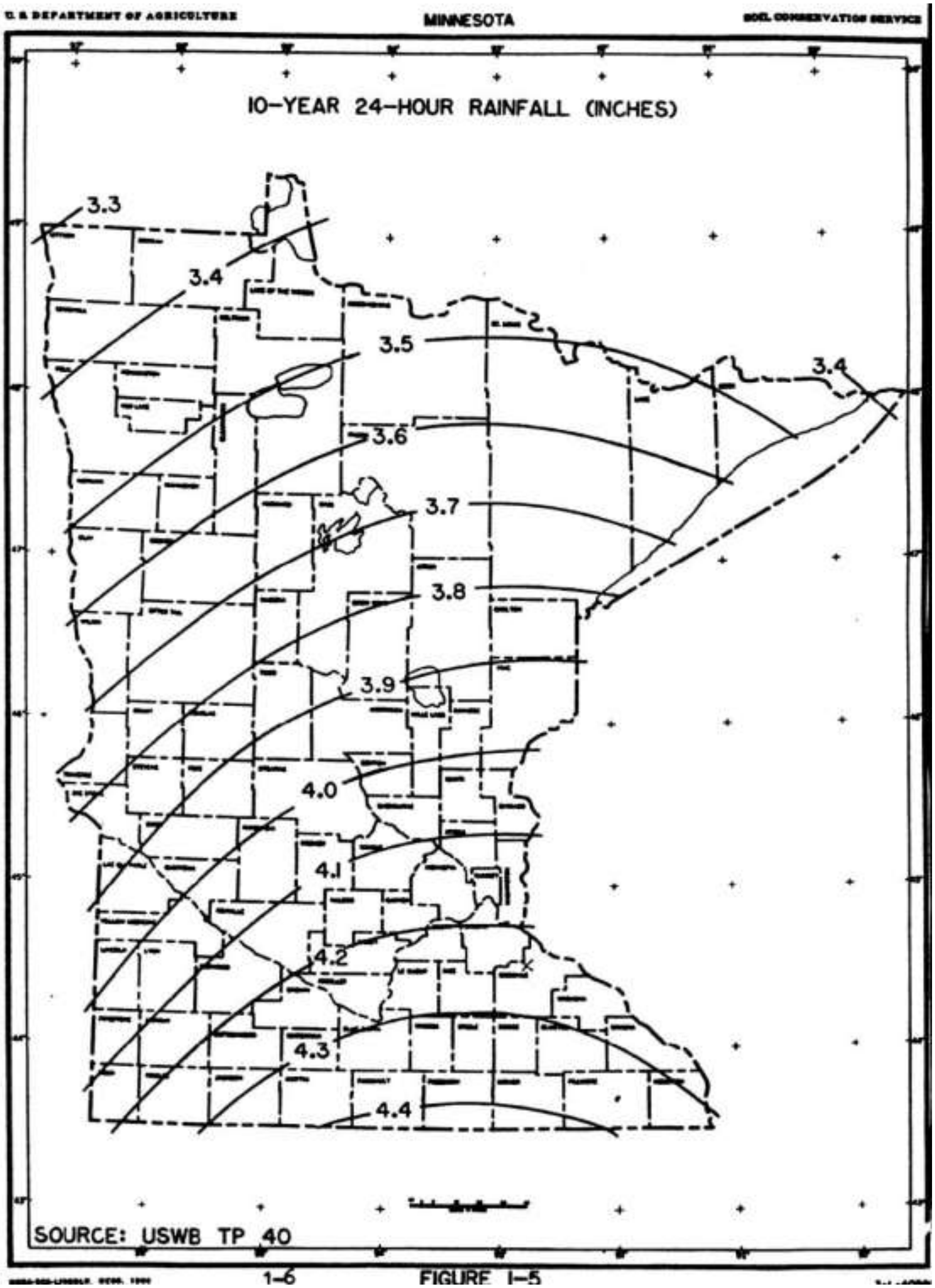

Figure 8. 10-Year 24-Hour Rainfall Throughout Minnesota

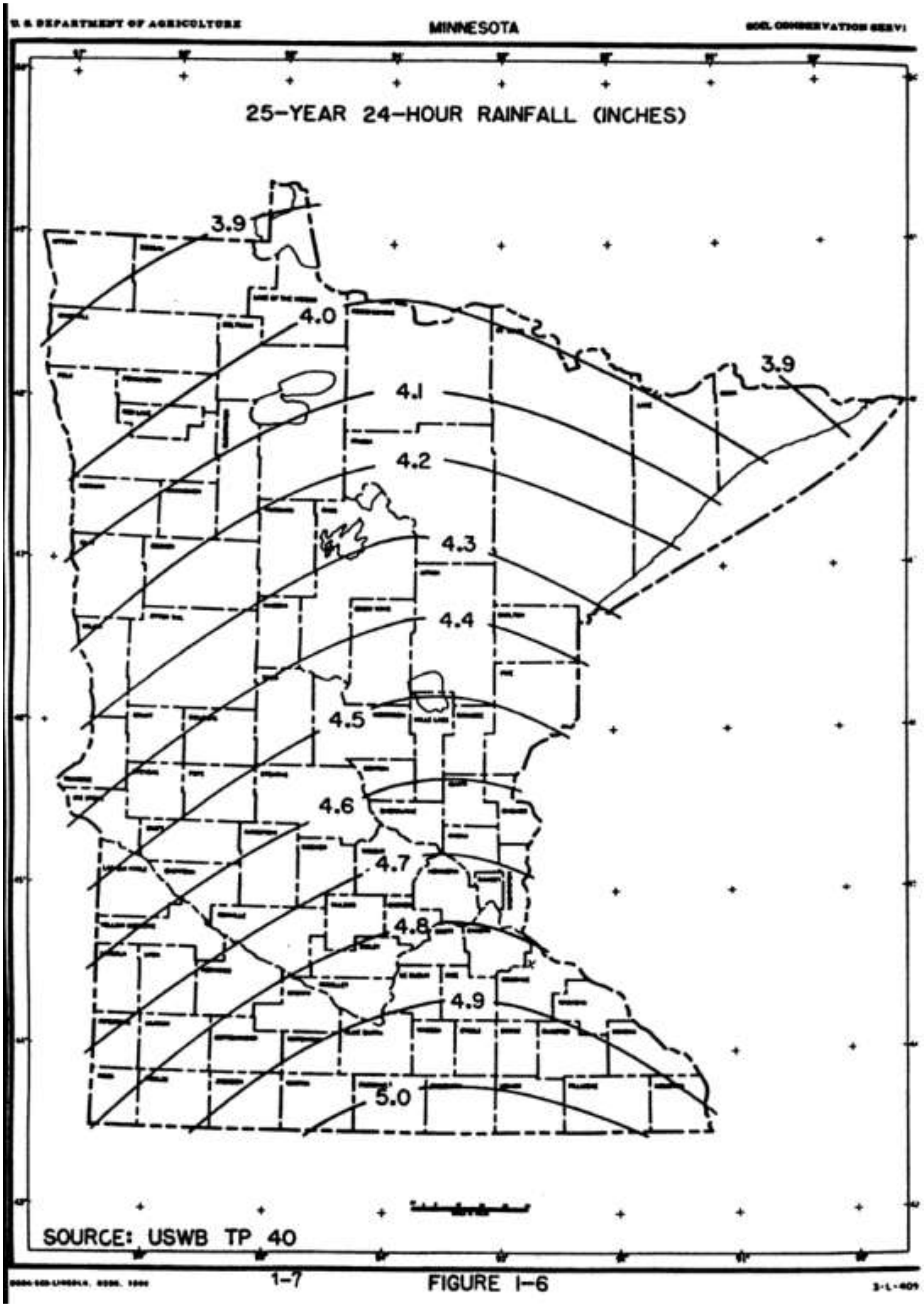

Figure 9. 25-Year 24-Hour Rainfall Throughout Minnesota

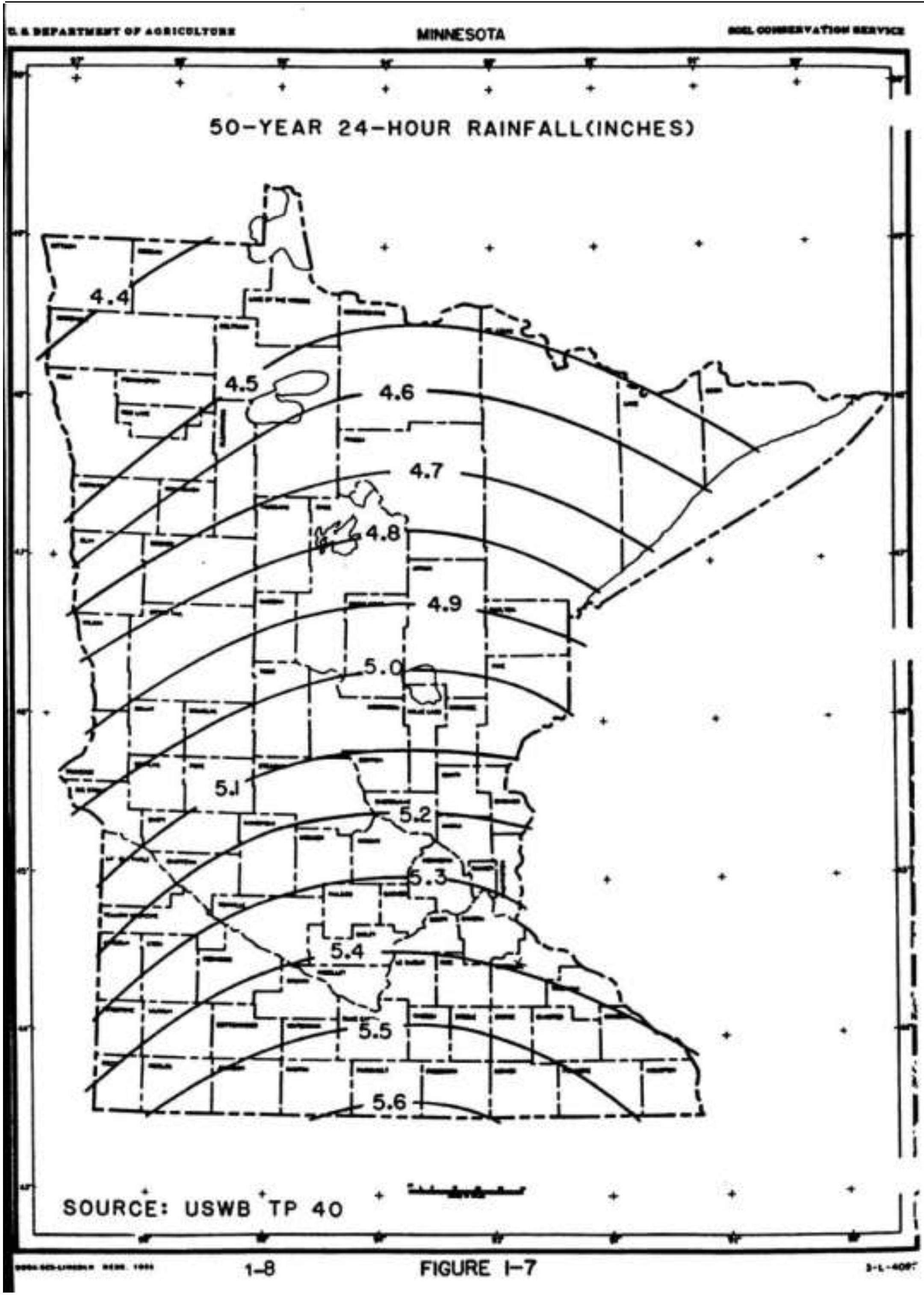

Figure 10. 50-Year 24-Hour Rainfall Throughout Minnesota

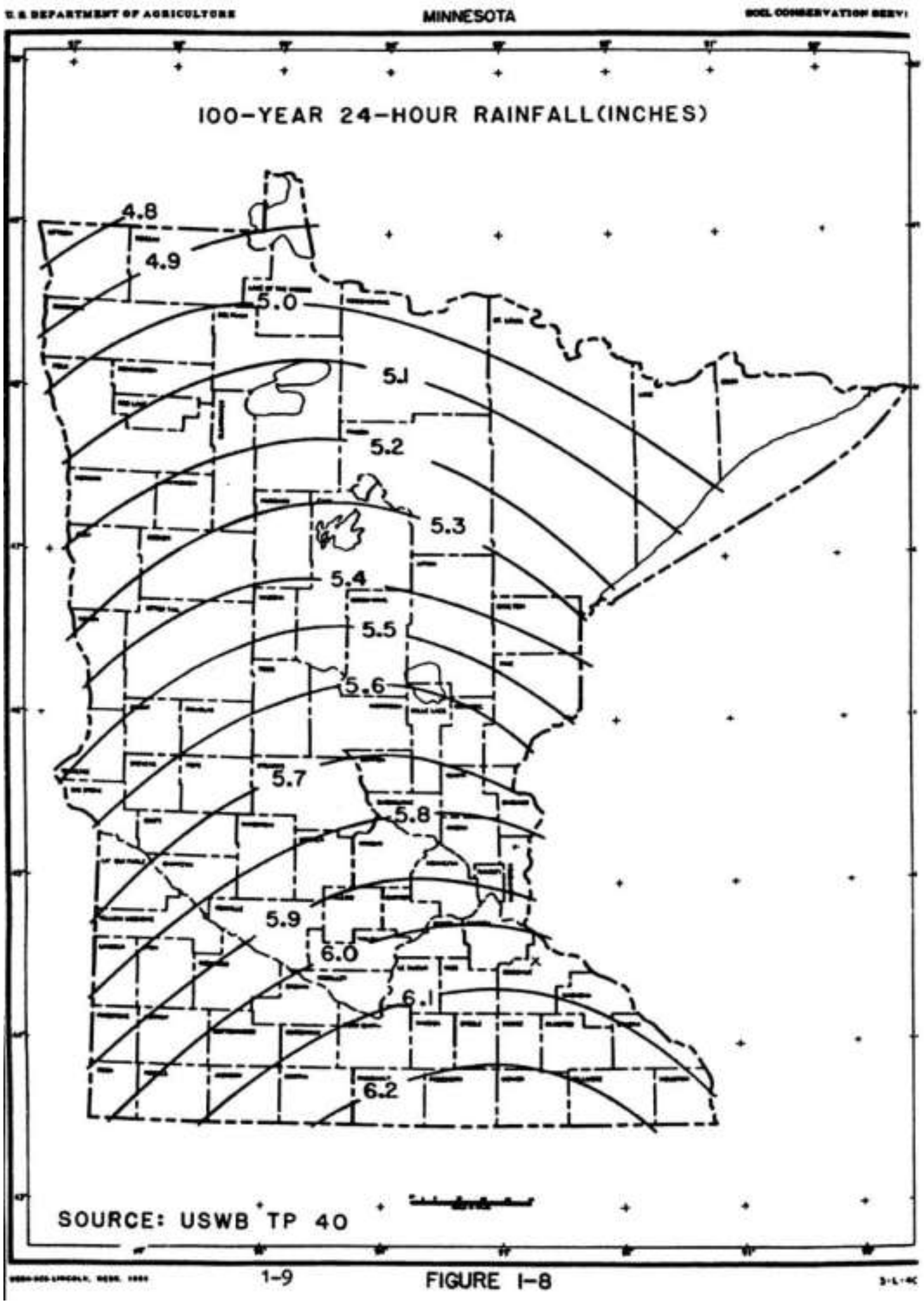

Figure 11. 100-Year 24-Hour Rainfall Throughout Minnesota

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