REGION H
Water Planning Group

Drought Management Study

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July 2009
AECOM Job No. 60072790

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for

Region H Water Planning Group

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Section 1 – Introduction

Traditionally, water policy and planning in Texas has focused primarily on "supply-side" strategies, that is, the development of supply and/or infrastructure to meet projected demands during critical droughts. While water conservation is often recommended and implemented as a "demand-side" strategy to meet portions of identified needs, the temporary curtailment of demands during drought has not been closely examined as a potential water management strategy. An important policy issue is whether successful implementation of drought contingency measures has the potential to reduce water demands during critical drought periods, possibly delaying or eliminating the need for additional sources of water supply.

The Region H Water Planning Group (RHWPG) requested and received funding from the Texas Water Development Board (TWDB) to conduct three studies in advance of the third five–year update of the Region H water supply plan. One study focused on evaluating the impacts of future water management strategies on freshwater inflows to Galveston Bay and on evaluating the impacts of instream flow requirements for future water management strategies. A second study focused on evaluating the feasibility of using available "interruptible" surface water supplies as a substitute for existing firm water supplies for certain uses, notably irrigated agriculture. The third study, which is the subject of this report, focused on evaluating the efficacy and impact of drought contingency (a.k.a. drought response) measures as a potential water management strategy in Region H. The key question addressed by this study is:

Can implementation of drought contingency measures within Region H during critical drought periods be used in lieu of other water management strategies to meet projected water demands?

The scope of work for the Region H drought management study was divided into two primary tasks. The first task focused on evaluating the efficacy or effectiveness of drought contingency plans adopted and implemented by municipal water suppliers within Region H, elsewhere in Texas, and nationally. The second task consisted of a quantitative evaluation of the potential impact of drought response measures on major water supply reservoirs in Region H, namely Lake Conroe, Lake Houston, Lake Livingston and the proposed Allens Creek Reservoir. Specifically, Texas Commission on Environmental Quality (TCEQ) water availability models were used to analyze reservoir conditions (i.e., levels and storage volumes) during critical drought periods both with and without implementation of drought response measures. The findings of these analyses are presented herein.

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Section 2 – Essentials of Drought Contingency Planning

Drought is a natural and recurring meteorological phenomenon where precipitation is significantly below "normal" for a period of time. Relatively mild, short-duration droughts are common throughout Texas and typically result in relatively mild impacts. However, extended severe drought conditions can have serious impacts on water supplies, water suppliers, and water users including:

- Reduction in available water supply leading to shortage conditions;
- Increases in water demand, particularly for seasonal demands such as landscape irrigation;
- Stress on water utility infrastructure due to elevated seasonal peak water demands relative to capacity limitations of water supply infrastructure;
- Deterioration of source water quality;
- Lifestyle and financial impacts to water users associated with restrictions on non-essential water uses (e.g., loss of landscaping); and
- Financial impacts on water suppliers due to reduced revenues from water sales during periods of water demand curtailment.

2.1 Key Principles of Drought Contingency Planning

By law, public water supply systems, wholesale water providers, and irrigation districts in Texas are required to adopt drought contingency plans. TCEQ administrative rules define a drought contingency plan as *"a strategy or combination of strategies for temporary supply management and demand management responses to temporary and potentially recurring water supply shortages and other water supply emergencies".* TCEQ rules and associated guidance documents for drought contingency planning embody several key principles including:

- Drought and its potential impacts on both water supply and demand, as well as water supply infrastructure, can be anticipated;
- Drought response measures and implementation procedures can be defined in advance of drought;
- Through timely implementation of drought response measures it is possible to avoid, minimize, or mitigate the risks and impacts of water shortages and other drought-related water supply emergencies;
- All water demands are not of equal value or importance, some can be considered essential to public health and safety or to the economy while others can be considered non-essential or discretionary; and
- Drought contingency plans should be tailored to the unique circumstances of each water supplier (e.g., vulnerability of water supply and/or infrastructure to drought, end-users and demand characteristics, objectives, etc.).

2.2 Common Elements of Drought Contingency Plans

Notwithstanding the aforementioned principle that drought contingency plans should be tailored to each water supplier's unique circumstances, there are a few elements that are more or less common to all drought contingency plans. These include:

- Criteria and procedures for determining when to initiate and when to terminate drought response measures. These are typically referred to as drought triggers. Common examples of drought triggers include indicators of supply availability (e.g., quantity of water supply remaining in a source) and demand indicators (e.g., daily demand relative to infrastructure capacity).
- Successive stages of drought response that require the implementation of increasingly stringent measures in response to increasingly severe drought conditions. A typical drought contingency plan will have an initial stage of voluntary measures followed by two or three successive stages of increasing stringent mandatory measures.
- Demand reduction goals or targets for each stage.
- Predetermined drought response measures for each stage that may include supply management, such as the temporary use of an alternative water source, and/or demand management, such as restrictions on non-essential water uses.
- Procedures for plan implementation and enforcement.
- Public information (e.g., notification) and education.

Most drought contingency plans place a heavy emphasis on "demand management measures" that are designed to reduce water demands by means of curtailment of certain uses. It's important to note that demand management in this context is distinctly different from water conservation, although the terms are often used interchangeably. The objective of water conservation is to achieve lasting, long-term reductions in water use through improved water use efficiency, reduced waste, and through reuse and recycling. By contrast, demand curtailment is focused on temporary reductions in water use in response to temporary and potentially recurring water supply shortages or other water supply emergencies (e.g., equipment failures caused by excessively high peak water demands). Common approaches to water demand curtailment, applied individually or in combination, include:

- Prescriptive restrictions or bans on non-essential water uses and waste. In a municipal setting, such restrictions commonly target landscape irrigation, car washing, ornamental fountains, etc.
- Use of water pricing strategies, such as excess use surcharges, to encourage compliance with water use restrictions or to penalize excessive water use.
- Water rationing, where water is allocated to users on some proportionate or pro rata basis.

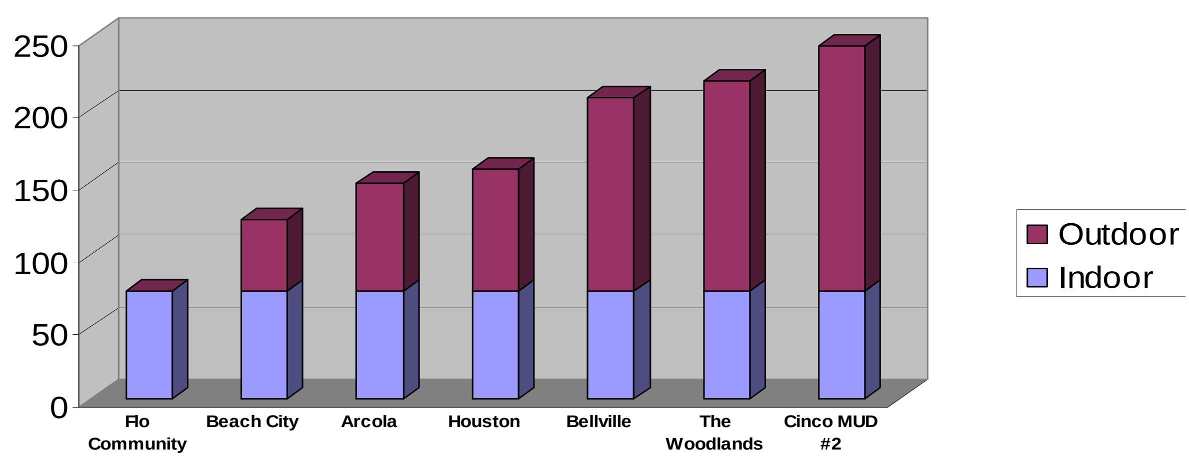
2.3 Commentary of the Efficacy of Drought Response Measures

The scope of work for this study includes several sub-tasks which, taken together, are intended to provide an assessment of the "efficacy" or effectiveness of drought response measures. It's important to emphasize that quantifying or predicting the effectiveness of demand-side drought response measures is very difficult owing in large part to the variability of municipal water use within and among communities; variability that is commonly attributed to differences in climatic, demographic, and socioeconomic characteristics. In particular, since most demand curtailment measures target seasonal water uses, such as lawn watering, it stands to reason that the effectiveness of such measures is dependent on and will vary greatly according to the seasonal water use characteristics of different communities. Simply stated, a drought response measure applied in one community likely will not produce the same effect when implemented in another community with different seasonal water use characteristics.

As demonstrated in Figure 2-1, per capita municipal water demands for communities in Region H vary widely and, if one makes the rough assumption that non-seasonal (e.g., indoor) water uses are more or less the same in each community, then the differences in per capita water demand can be attributed largely to seasonal water uses. This assumption ignores city size, socioeconomic conditions, and the influence of commercial and institutional water use that is part of the per capita demand of some entities. The outdoor usages shown in Figure 2-1are estimated assuming the per capita water demands of Flo Community WSC as an estimate of typical indoor water use. From this small sample, it's also apparent that the relative degree of urbanization and affluence of communities are important determinants of seasonal water demand. For example, affluent suburban communities invariably show higher per capita water demand owning in large measure to housing characteristics such as the predominance of single-family detached residences on lots with relatively large landscaped areas.

Isolating the effectiveness of specific drought response measures is also problematic in that most municipal drought contingency plans employ multiple measures, such as water use restrictions, public education, and perhaps pricing policies, that in combination have synergistic rather than additive effects. This is further complicated by behavioral factors that may influence the effectiveness drought response measures, either singly or in combination. For example, it is has been reported that the degree to which the public understands and believes there is a "real" water supply problem can significantly affect the extent of both voluntary and mandatory compliance with water use restrictions. In other words, the effectiveness of public information and education efforts, or lack thereof, will have a direct impact on the effectiveness of other drought response measures. Similarly, the degree to which mandatory water use restrictions are enforced can also have direct bearing on the effectiveness of such restrictions in reducing water demand; that is, aggressive enforcement will generally result in a higher degree of compliance and greater demand reductions than lax enforcement. The effects of enforcement are typically reflected in the structure of municipal drought contingency plans where the first stage is a request for voluntary compliance with prescriptive water use restrictions that become mandatory in the second stage of the plan. Accordingly, it is common to establish a lower water demand reduction goal for Stage 1 and a higher goal for Stage 2 based on the expectation of enforcement, and greater compliance, with mandatory restrictions.

Figure 2-1. Example per Capita Municipal Water Demands in Regions H



Yet another consideration that may influence the effectiveness of drought response measures is the type of problem addressed by and the specific objectives of a drought contingency plan. For municipal water suppliers in Texas, "real" water supply shortages are not a common occurrence during droughts. Rather, by far the most prevalent drought-related problem faced by municipal water suppliers are elevated seasonal peak water demands and the stress such demands can place on the limited capacity of water utility infrastructure (e.g., treatment, storage, and/or distribution).

Accordingly, the most common objective of municipal drought contingency plans is to “shave” peak water demands in order to reduce stress on infrastructure and thereby avoid or minimize impacts on water service, such as equipment failures or low water pressure. While peak shaving is also typically accomplished with restrictions on seasonal water uses such as landscape irrigation, it’s important to note that degree of demand reductions needed to address a “peaking problem” may be much less than what would be needed in an actual water shortage situation. For example, in a true water shortage situation limiting lawn water to one or two days per week, or an outright ban, may be required to achieve the desired reduction in water use while an alternate day (e.g., odd-even) watering schedule may be sufficient to reduce peak water demand to safe levels.

The approved scope of work for this study also directs that the effectiveness of drought response measures be expressed in terms of reductions in per capita water use. However, upon further study during the course of this study, it was determined that this is problematic for several reasons. First, most drought contingency plans are “goal based” meaning that demand reduction targets are typically established based on the degree of reduction estimated to be needed for each stage of the plan. For example, an analysis of the vulnerability of a water supply to drought may reveal that a 10 percent reduction is sufficient to minimize the risk of shortage when supply availability is within a certain range (e.g., between 50 and 70 percent of normal) and that a 20 percent reduction is required when supply availability is further reduced (e.g., between 30 and 50 percent of normal).

Second, the typical expression of demand reduction goals in a municipal drought contingency plan is a percentage reduction, rather than a per capita reduction goal. Also, because most municipal drought contingency plans in Texas focus primarily on reducing seasonal peak water demands, percent reduction goals are typically measured (when measured at all) on a “before and after” basis in which overall water demand after implementation of drought response measures is compared to overall water demand immediately prior to implementation of drought response measures. This approach does not lend itself to quantification of “savings” in terms of per capita use. Furthermore, there is significant potential for error in the quantification of demand reductions from drought response measures in terms of per capita use, due to inconsistencies in water use reporting (e.g., inclusion of non-municipal uses supplied by public water systems), inaccurate population estimates, variations in billing cycles, and variability of unaccounted-for water use (e.g., meter error, water loss).

Section 3 – Efficacy of Drought Management Measures

The first phase of the study included the following tasks:

- Obtain a list of systems on the TCEQ drought impact list
- Determine system size in terms of connections, population and water use information.
- Survey officials of drought impacted systems.
- Compare water use records before and after implementation of drought management measures
- Research national publications for information on the efficacy of drought management measures in other climates
- Develop summary of commonly used drought management measures and estimate corresponding water savings

3.1 TCEQ Drought Impact List

A list of public water systems impacted by drought was obtained from TCEQ along with water utility data such as the number of service connections, estimated population, and average day usage. The information obtained from TCEQ contained records for public water utilities throughout the State for the period 1996 to 2008. This section presents information about public water systems within Region H that were included on the TCEQ list one or more times during this period.

As shown in Figure 2, a significant number of public water systems in Region were on the TCEQ drought impact list and implemented drought measures during the years 1998 (62 systems), 2000 (35 systems) and 2005 (39 systems). The counties that recorded the most public water systems on the list are Harris and Montgomery counties (Figure 3). Together, Harris and Montgomery Counties accounted for approximately 55 percent of the systems on the drought impact list. Approximately 90 percent of the water systems on the drought impact list serve populations less than or equal to 10,000 people, as shown in Figure 4, and have 5,000 connections or fewer, as shown in Figure 5. TCEQ records also indicate that the list is comprised mostly of public water systems that are supplied by groundwater.

The largest public water utility on the TCEQ drought impact list is the City of Houston, which implemented voluntary water restrictions in July 2000 in response to high customer demands. In addition to the City of Houston, several other Region H Wholesale Water Providers (WWPs) have been on the drought impact list. The City of Galveston placed “mild rationing” restrictions on customers both in July 1996 and July 2000. The Clear Lake City Water Authority implemented “mild rationing” restrictions in September 1999 and in July 2000. The San Jacinto River Authority placed “mild rationing” restrictions on customers in The Woodlands in July 1998 that are supplied with water from the Jasper and Evangeline aquifers.

Surveys of Major Public Water Systems discussed in Section 3.2 indicated that none of the Region H public water systems that were on the TCEQ drought impact list over the period from 1996 to 2008 experienced actual water shortage conditions. Rather, it appears that these water systems were placed on the list because of high seasonal peak water demands and attendant problems or concerns with water production infrastructure. The majority of Region H public water systems on the TCEQ drought impact list are municipal utility districts (MUDs), water supply corporations (WSCs), subdivisions and rural municipalities that rely on groundwater from local wells. Sustained high peak water demands during the summer months often create a strain on groundwater supplies, not so much in terms of the availability of supply but rather in terms of groundwater production capacity, indicating a need perhaps for additional wells to increase delivery capacity or deeper wells to compensate for greater than normal draw down. Public water systems that rely on surface water often experience similar problems in terms of limited capacity to treat raw water and/or distribution system capacity limitations.

Figure 3-1. Number of Utilities on TCEQ list by year

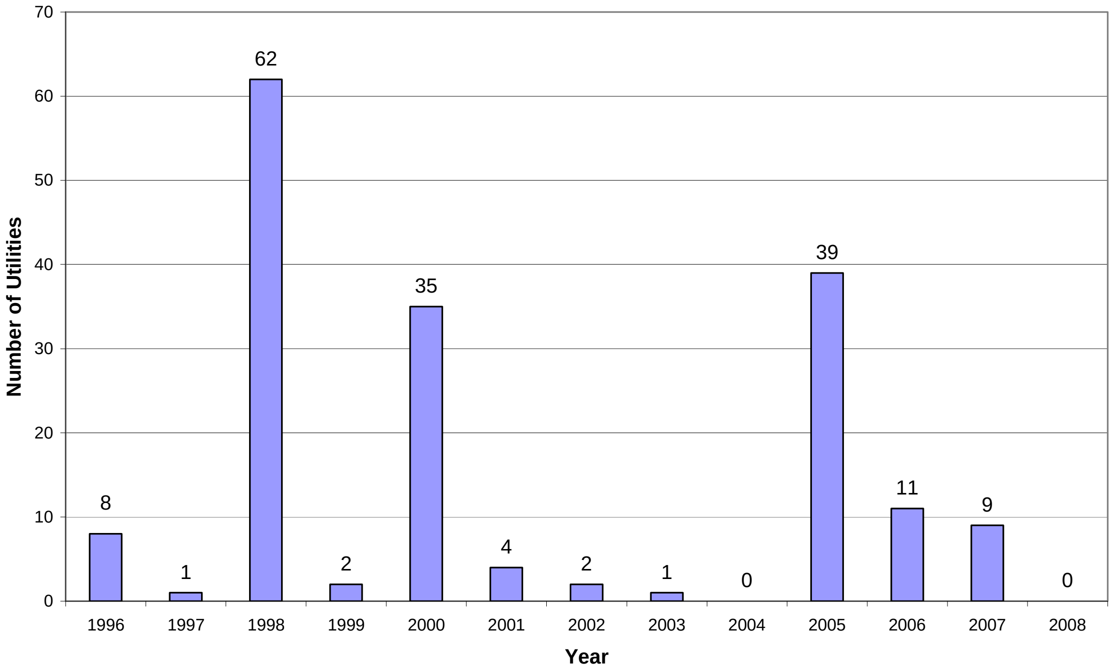


Figure 3-2. Utilities of County

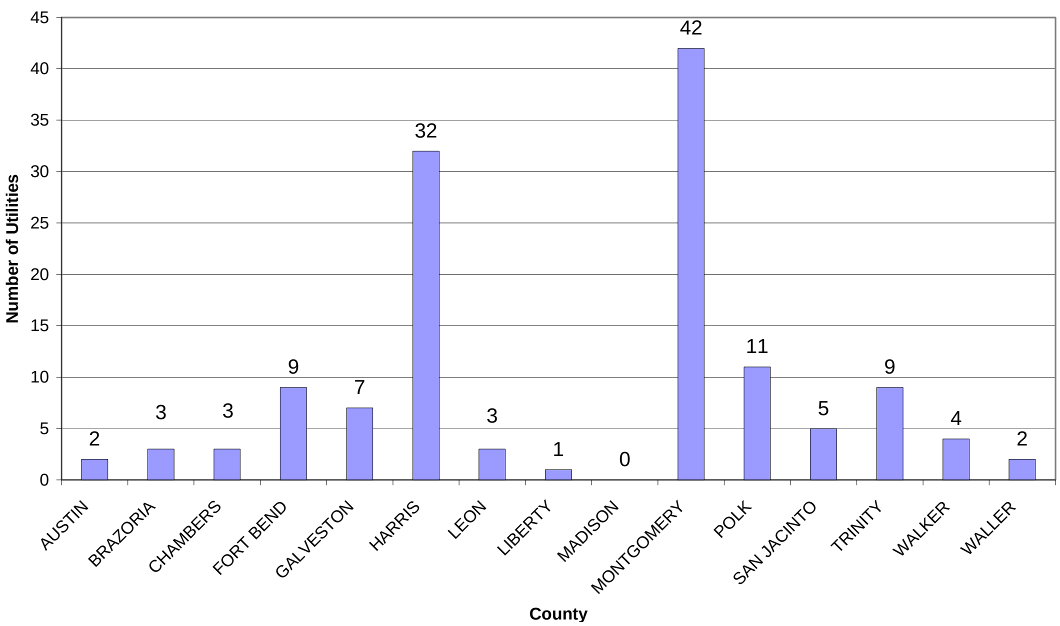


Figure 3-3. Population Distribution

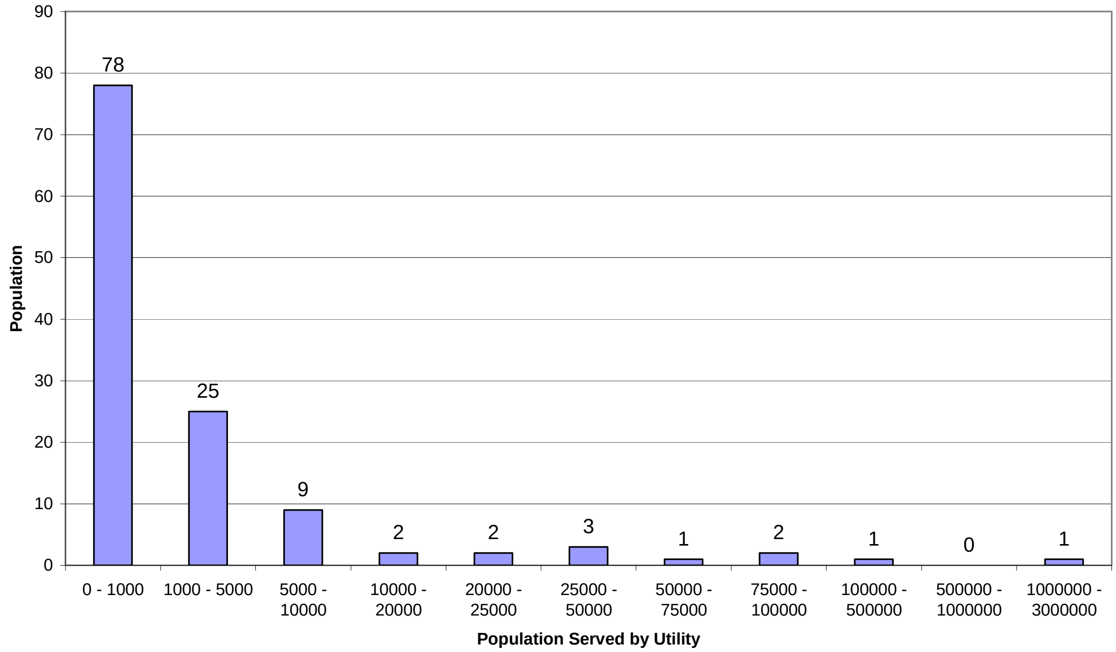


Figure 3-4. Connections Distribution

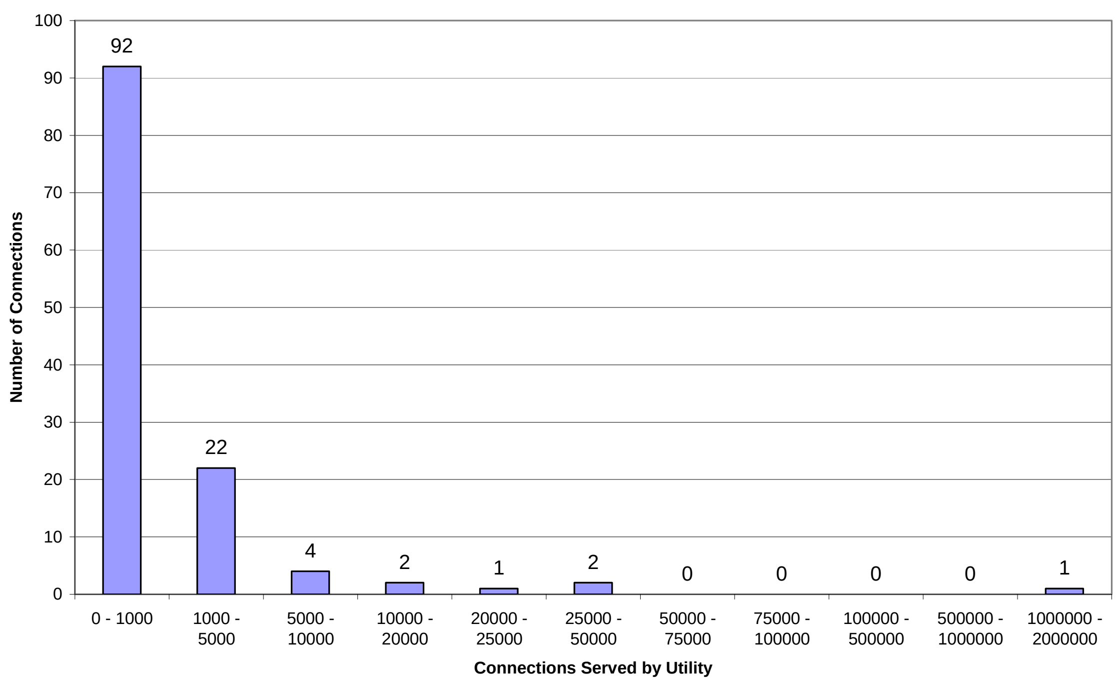
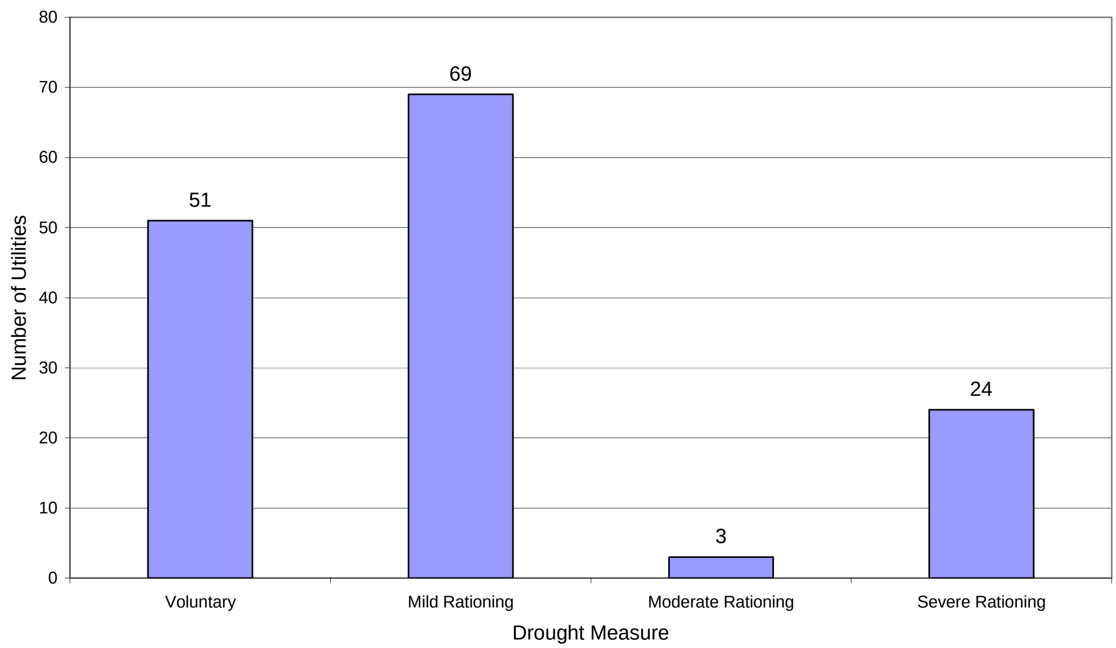


Figure 3-5. Drought Measures



3.2 Survey of Public Water Systems

The TCEQ drought impact list was used to select utilities in Region H that have implemented drought management measures at one time or another over the period from 1996 to 2008. Selected utilities were surveyed to obtain additional information including:

- Per capita water demands before and after drought measures
- Records of drought measures implemented
- Water Supply Sources
- Nature of Problem
- Lessons learned

Initially, only public water systems with surface water supplies were surveyed. The list was expanded to include municipal utility districts (MUDs) after initial attempts to contact those systems yielded few results. Overall, the information obtained through the survey indicates that water systems in Region H have little or no direct experience with actual water shortage conditions. As indicated, available information suggests that the Region H water systems on the TCEQ drought impact list have implemented drought response measures only to temporarily reduce peak demands to alleviate stress on limited infrastructure. A few water systems have implemented severe restrictions in response to emergencies situations including outages, contamination, and low water pressure. The City of Houston, for example, has twice implemented voluntary water use restrictions over the past decade in response to high daily demands during summer months. No data was available to quantify the effects that voluntary reductions had on the per capita daily demand. A discussion with representative of the City of Galveston revealed the most recent drought measures in 1996 and 2000 were also the result of infrastructure limitations. During 1996, failure of a transmission line delivering water to Galveston resulted in the implementation of mild rationing measures. During 2000, water deliveries were unable to keep pace with the City's peak demands resulting again in the implementation of mild rationing, as well as the purchase of additional groundwater. No information was available with respect to the level of enforcement and per capita demands prior to, during, and after the implementation of drought measures. Information regarding the effects of drought response measures on water demands was also not available from the cities of Lake Jackson, Clute and Magnolia. Due to the lack of information on per capita demands before, during, and after the implementation of drought contingency measures, historic water use records from the TWDB were used to asses the impacts on the annual per capita daily demand.

3.3 Water Use Records Before And After Drought Management Measures

Data from TWDB was used to estimate the impacts of drought management measures on annual per capita daily water demands. The annual gallons per capita daily demands (gpcd) for several municipalities in Region H were trended and analyzed before and after the utility reported drought management measures to TCEQ. Major utilities in Region H were analyzed to determine the effect, if any, that drought response measures may have had on annual water demands. Annual water use for Corpus Christi and San Antonio was also compared to analyze the effects of drought response measures in other areas of the state.

Figure 3-6. City of Houston gpcd Water Use

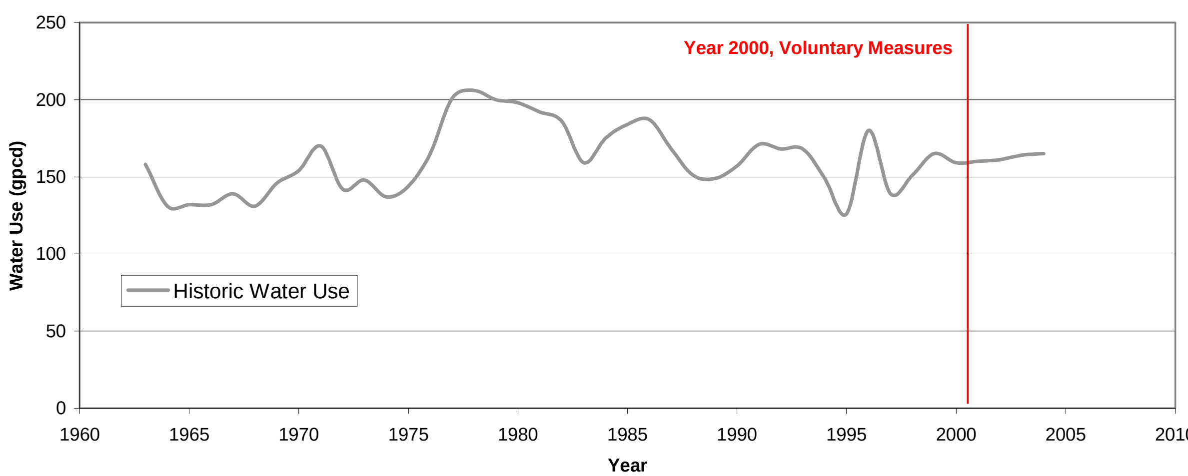


Figure 3-7. City of Galveston gpcd Water Use

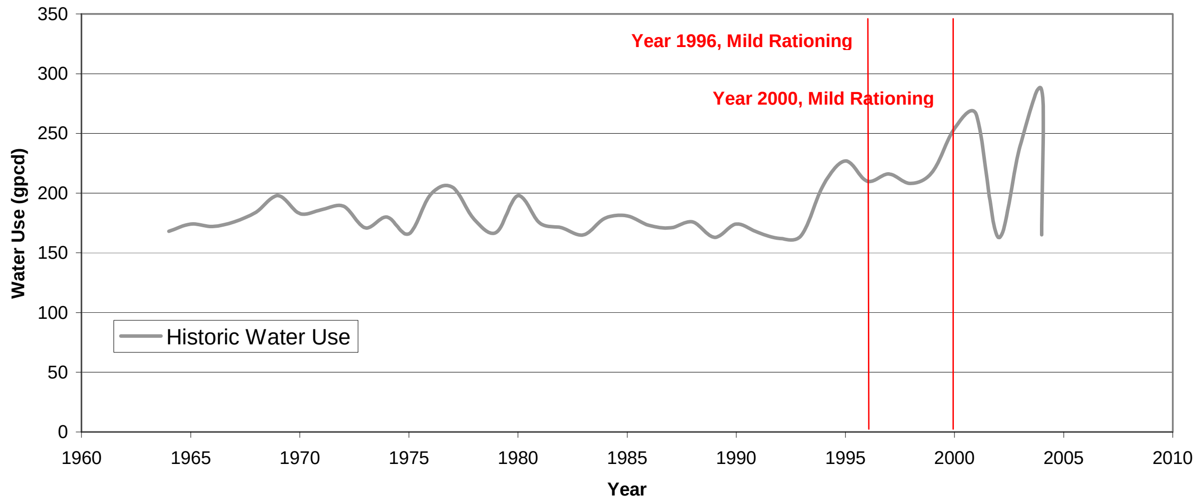


Figure 3-8. League City gpcd Water Use

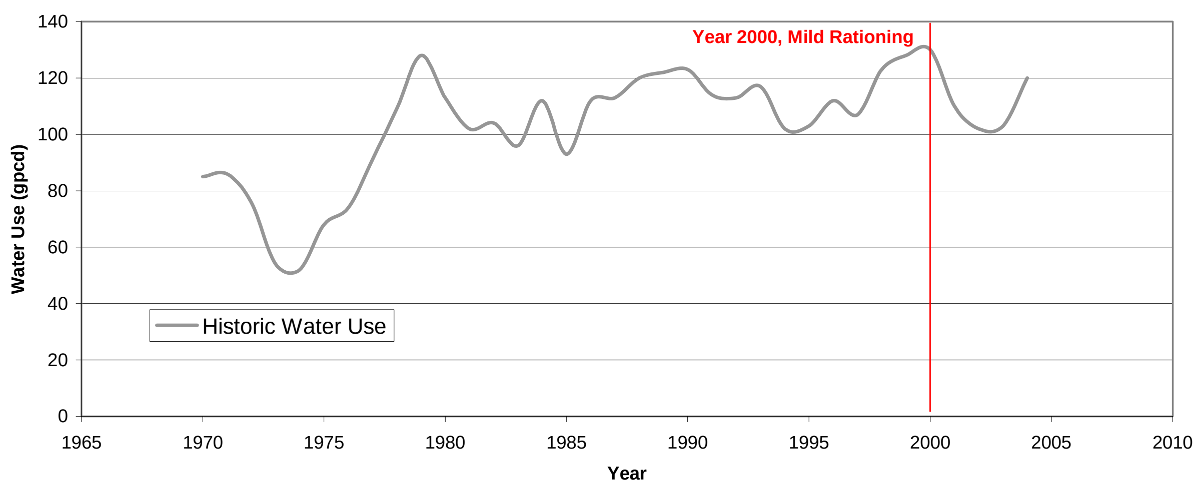


Figure 3-9. Friendswood gpcd Water Use

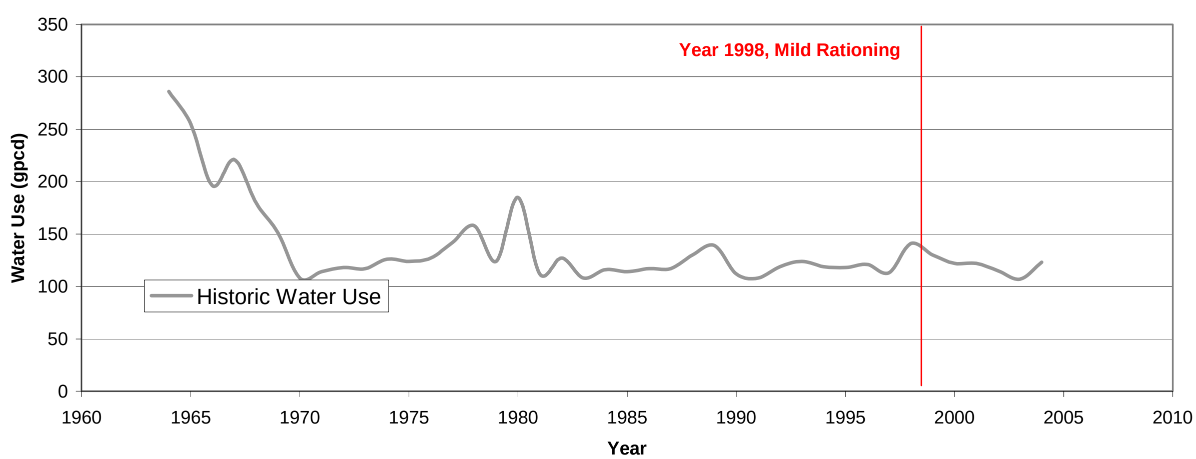


Figure 3-10. Lake Jackson gpcd Water Use

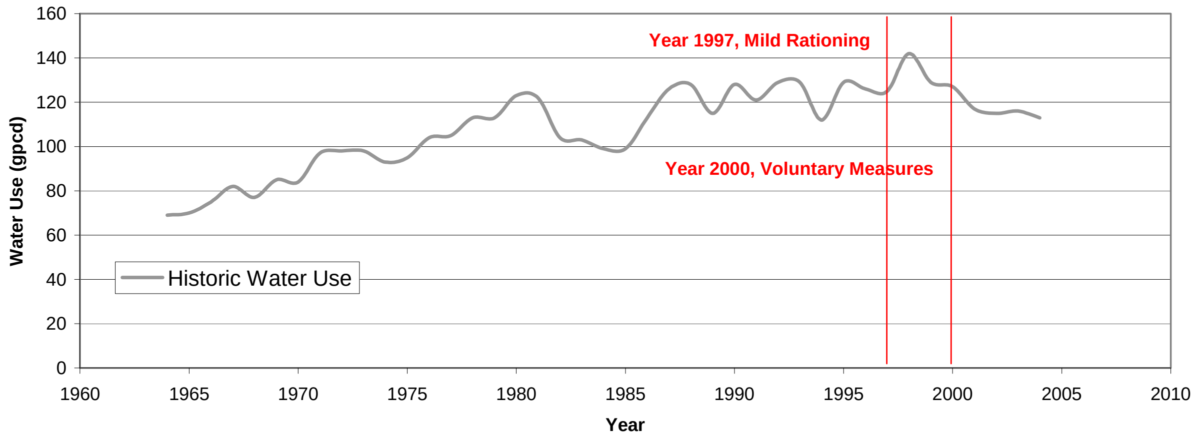


Figure 3-11. Corpus Christi gpcd Water Use

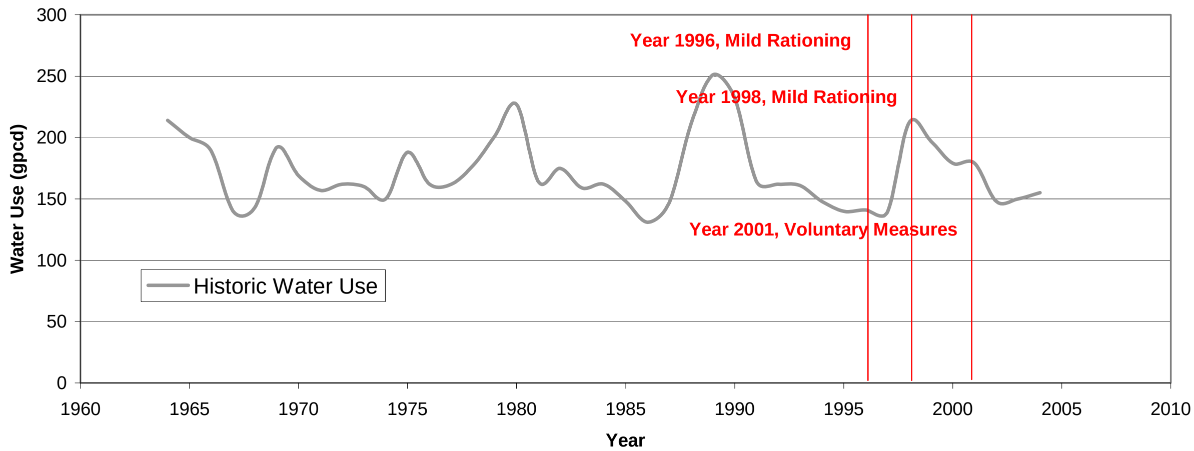
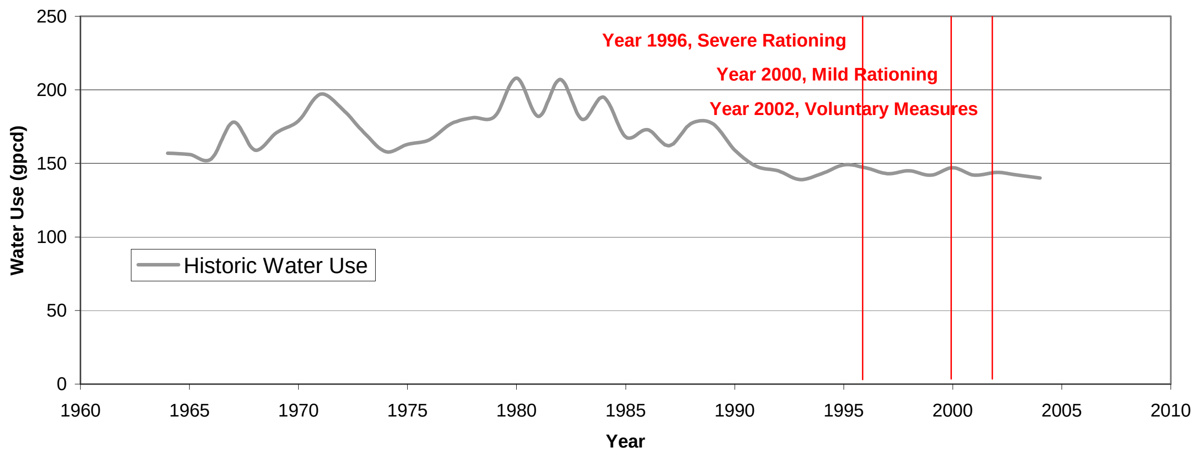


Figure 3-12. Corpus Christi gpcd Water Use



Graphs of annual per capita daily demands for utilities in Region H illustrate the difficulty in quantifying the effects of specific drought management measures. There does however, exists some evidence that the implementation of a collection of management measures (drought stages) may have a measurable impact on per capita daily demands. Voluntary and mild rationing measures appear to have little or no impact on annual gpcd recorded for the City of Houston and the City of Galveston. However, there does appear to be an impact on annual gpcd for the cities of Friendswood, Lake Jackson, and League City. Mild rationing measures implemented by the City of Friendswood in the year 1998 may have had some effect on reducing peak daily demands but likely did not reduce the average annual gpcd likely due to a short term implementation of drought response measures. The League City drought plan is triggered when daily water demand equals or exceeds a set percentage of the system operating capacity for some duration. The drought plan is seasonal by nature designed to manage peak day demands. There does appear to be a reduction in annual per capita demands of approximately 20% in the years after 2000 most likely due to wetter hydrologic conditions. Without performing a detailed analysis of daily water production records, daily rainfall, and the effects of long term conservation measures (activities beyond the scope of this study), it is not feasible to isolate the impacts of individual drought plans and specific response measures.

Recent measures implemented by the City of Corpus Christi in 1998 and 2001 appear to have reduced annual per capita daily demands by nearly 15% in the following years. As mentioned previously, the effects of drought response measures can not easily be disaggregated from the effects of increases in rainfall and implementation of conservation measures. Mild rationing and voluntary measures implemented in San Antonio appear to have little effect on annual gpcd. The measures were implemented to reduce peak daily demands during summer months. This also illustrates "Demand Hardening" a phenomenon that reduces the effectiveness of temporary drought measures as a result of frequent implementation. The San Antonio Water Authority has implemented year-round water restrictions that limit landscape irrigation, washing vehicles and impervious surfaces. The use of year-round water restrictions in San Antonio may have reduced the effects of temporary drought measures.

Average annual municipal demands are insufficient for developing a quantitative analysis of drought response measure effects. As previously discussed, quantifying the effects of drought response measures is extremely difficult due to differences in climates, demographics, and socioeconomic factors. The data presented in this section does not allow the effects of drought response measures to be disaggregated from other factors including rainfall, conservation measures, and seasonality of non essential municipal water use.

3.4 Region H Existing Drought Contingency Plans

3.4.1 Trinity River Authority (TRA) DCP

The Trinity River Authority (TRA) currently supplies raw water from Lake Livingston to the Cities of Trinity, Grovetown, Glendale, Trinity Rural, Riverside water Supply Corporations, and Westwood Shores MUD. Purchased water from Lake Livingston is treated at the Trinity County Regional Water Supply System. The TRA drought plan authorizes the General Manager to initiate or terminate drought and other emergency water supply measures to protect public health, safety and welfare. Drought stages are triggered by reductions in the normal conservation storage measured by the lake water surface elevation. Three drought stages implement demand management measures to reduce demands by 5 percent, 15 percent and 25 percent when the normal conservation storage level of the reservoir is below 80 percent, 70 percent, and 60 percent respectively. The demand management measures that can be utilized by TRA during drought stages include: requests for voluntary reductions in water use, encouraging customers to use alternative supplies, mandatory reductions of non-essential water use, and pro-rata curtailment of diversions and deliveries.

3.4.2 San Jacinto River Authority (SJRA) DCP

The San Jacinto River Authority (SJRA) drought plan was obtained during the development of this study. The SJRA drought contingency plan is organized into two sections. The first section focuses on municipal demands in the Woodlands and sets drought triggers based mainly on infrastructure capacity including combined pumpage and elevated/ground storage levels. The second part of the SJRA drought contingency plan focuses on Lake Conroe and the Highlands Canal System. Trigger conditions for each successive drought stage are based on conservation storage. Stages 1 – 3 set demand reductions of 10%, 15% and 20% based on conservation storages of 70%, 55% and 40% respectively. A fourth stage is triggered by a failure of the Highlands Canal System, natural or man-made disasters.

3.4.3 Brazos River Authority (BRA) DCP

The Brazos River Authority drought plan identifies three levels of drought severity and identifies specific actions to be implemented. The BRA plan considers each reservoir in the BRA/COE system individually and together as a system. For an individual reservoir a drought stage is initiated when the reservoir storage drops below a trigger condition *and* sufficient data exists to suggest that the reservoir capacity could be further reduced below the next stage trigger within 12 months. The requirements for initiating a group of reservoirs or the entire Authority's system follow the same pattern. Stage three however, is initiated when a reservoir, group of reservoirs or the system is at or below the stage three trigger. Triggers for stage 1, 2 and 3 correspond to reoccurrence frequencies of 20%, 10% and 5% based on statistical analysis of each reservoir.

3.4.4 Region H DCP Conflicts

The previous sections highlighted the drought contingency plans of the major wholesale water providers with existing and future supplies in Region H. It is evident that existing drought contingency plans in Region H utilize several different triggers to initiate successive drought stages and demand management measures. SJRA and TRA define drought triggers based on percentage of normal conservation volume and are easily observable by monitoring water surface elevations. BRA defines trigger levels for each reservoir in the Authority's system based on statistical analysis, while the City of Houston defines drought triggers based on the number of months existing surface and ground water supplies could continue to meet the current demands. Because the City of Houston owns water rights in all three existing reservoirs and in the future Allens Creek reservoir, the supplies in each lake are simultaneously an important part of two drought contingency plans. Lake Conroe is a focal point of the SJRA drought plan and part of the City of Houston's combined system storage. Lake Livingston is shared by TRA and the City of Houston and Allens Creek is projected to be shared by the City of Houston and BRA.

3.5 National Research

In addition to compiling information from water supply systems within Region H, several utilities across the nation were surveyed while making sure to account for various geographic and weather conditions. Utilities surveyed included the City of Santa Barbara, CA; the City of Peoria, AZ; South Florida water management district; the City of San Diego, CA and the City of Denver, CO.

3.5.1 Santa Barbara, California

The Santa Barbara County Water Agency has no direct customers, the water Shortage/Drought Management Plan is necessary to coordinate the drought plans of local water providers. The Regional Plan describes the following specific actions to be undertaken by the Water Agency:

- Development of coordinated advertising campaign and public information materials
- Acceleration of low-flow fixture rebate programs
- Complete an inventory of potential surplus water available for exchange/sale to districts that may wish to augment their existing supplies
- Work with medium and small local water providers to complete water shortage plans using the USBR Water Shortage/Drought Planning Handbook developed by the Water Agency in 2003
- Hold public workshops to allow local providers and the public a forum for discussing issues that water users may face during a drought
- Incorporate other actions in the plan as appropriate in response to future conditions

The County Water Agency will begin implementing the following drought contingency measures in conjunction with local water providers when local weather patterns result in three years of average or below average rainfall, or when asked to by local water providers, whichever occurs first. Different methods are prescribed to increase existing supplies, draw from reserve supplies, increase efficiency, modify operations, cooperate with other agencies, and implement demand reduction actions.

A study of eight water agencies in California analyzed the efficacy of various demand-side management policies implemented between 1989 and 1996 during California's statewide drought. The study included the San Francisco Water District, City of San Bernardino, Los Angeles Department of Water and Power, City of San Diego, and the City of Santa Barbara. The water agencies studied implemented various demand management strategies including the following:

- Public education and information campaigns
- Subsidies to encourage water efficient technologies
- Water rationing including price penalties
- Restrictions on non-essential water use

The study aimed at evaluating the relative performance of various demand-side management policies and assessing water policy implications. The following conclusions were reached:

- Demand reductions of 5% - 15% could be achieved by price increases and voluntary measures

- Demand reductions of greater than 15% would likely require larger price increases and water use restrictions
- Lower income households are likely to be more responsive to price increases
- Outdoor water use restrictions will likely have higher impacts in suburban communities

3.5.2 Peoria, Arizona

The Drought Contingency Plan for Peoria Arizona prescribes procedures and strategies when water supplies may not be able to supply demands as the result of below normal rainfall resulting in a water supply drought. The goals of the plan are to protect public health and safety, provide sufficient water to meet customer demands, share the impacts and hardships caused by drought equitably and in a proportion to the magnitude of the drought, minimize disruption of the economy, provide options for updating or changing the Drought Plan, and enforce city code so that drought related water reduction goals will be met.

The plan approaches droughts through triggers to different stages. A stage one “Water Watch” is triggered when the possibility exists that the City of Peoria Utilities Department will not be able to meet all of the water demands of its customers. Voluntary demand reductions and public education strategies are implemented to achieve a water use reduction of 5%. Stage two is a “Water Alert” implementing mandatory measures to achieve a 10% reduction in water use. Stage three is a “Water Warning” aimed at achieving a 15% reduction in water use by increasing mandatory restrictions.

3.5.3 South Florida Water Management District, Florida

The South Florida Water Management District (SFWMD) covers 16 counties in Southern Florida. A Phase I (moderate) water shortage requires water users to limit outdoor water use with the goal of reaching a 15% reduction in overall demand for water. A Phase II (severe) water shortage restricts outdoor water use with the goal of producing a 30% reduction in overall demand. Phase III (severe) water shortage restrictions have the goal of achieving a 45% water demand reduction. Specific methods for achieving reduction goals vary according to phase and user category. Water agencies in the South Florida Water Management District utilize various restrictions to achieve prescribed reduction goals including restrictions on: residential per capita consumption, non-essential utility use, power production water use, limits on commercial and industrial water use, agricultural water use, Landscape irrigation, recreation, and other non-essential water uses. The district also implements strategies to preserve and augment water supplies by making strategic water deliveries from Water Conservation Areas and regional canal systems, by protecting coastal well-fields from saltwater intrusion, maintaining fire protection capabilities in designated canals in rural areas, and meeting the needs of power generating plants.

Drought conditions in the year 2001 resulted in the District imposing Phase III restrictions with the aim at reducing water use by up to 45%. Phase III restrictions were initiated after Phase II policies reduced water use by 10%, well short of the 20% to 30% goal defined in the District’s Water Shortage Plan. Lake Okeechobee dropped to the lowest levels ever recorded, making it necessary for some public water supply utilities to modify pumps and intake lines to avoid the risk of not being able to supply water to homes.

3.5.4 San Diego, California

The San Diego County Water Authority (SDCWA) drought management plan was created after the drought of 1977-1976, when San Diego first experienced demands that were greater than its supplies. During that time, the Metropolitan asked for and received voluntary reductions in deliveries of 10% and began considering how to deal with future supply shortages. The DMP developed a "Drought Response Matrix Stages" to provide guidance to the Water Authority and its member agencies to select potential regional actions to lesson the severity of shortage conditions.

The potential actions for Stage 1 start with voluntary reductions. The voluntary stage would likely occur when Metropolitan has been experiencing shortages in its imported water supply and is withdrawing water from storage to meet normal demands. Stage 2 may occur in the third or fourth year during a dry period and may result in restrictions on water delivery. Stage 3 implements "mandatory cutbacks", triggered when demands are unable to be met. Stage 4 restricts water delivers for health and safety purposes only by drastically restricting deliveries.

3.5.5 Denver, Colorado

The Denver Drought Response Plan was the result of lessons learned from drought restrictions implemented in Denver Water's service area during drought conditions in 2002 and 2003. The plan approaches drought response from four perspectives-triggers, drought responses, public outreach, and internal communication.

Stage 1 is implemented when the reservoir storage is 80% or lower of expected July 1st conditions. The demand management policy includes requesting customers to voluntarily reduce their water usage by 10% and implement a public awareness campaign. Stage 2 occurs when the reservoir storage is 65% or lower than expected July 1st conditions. Response measures include a water use reduction goal of 30% for large-volume customers, industry-specific water restriction programs and a surcharge program to support the mandatory drought restrictions. Stage 3 results from reservoir storage less than 40% or lower of expected July 1st conditions. Responses include strict restrictions on outdoor water use, elimination of all nonessential water usage, and a water use reduction goal of 50% for large-volume customers. Stage 4 results from reservoir storage of 25% or lower than expected July 1st conditions. Response measures include limiting outdoor watering to monthly tree watering, elimination of nonessential water uses, and a water-rationing program to provide customers water for essential uses for indefinite period of extreme drought.

A 2004 study evaluated the effectiveness of water use restrictions implemented by several municipalities in Colorado. The 2002 drought surpassed the 1954 Colorado drought of record commonly used for planning in the state. The study focused on restrictions of lawn watering which reportedly accounted for more than half of annual residential water use. The study focused on municipal water providers including Denver Water, Aurora and Boulder. The study highlighted four findings.

- Mandatory restrictions reduced water demands by a wide range from 13% to 55%. The variance was possibly due to differences amongst the service populations and variations in restrictions and level of enforcement.
- Voluntary restrictions had marginal results. Net consumption actually increased in two cities after voluntary restrictions were implemented.
- The greatest reductions in terms of percentage were found in cities with the highest enforcement levels and limitations on outdoor watering.
- Every city studied was able to reduce per capita water use through use of water restrictions. The level of reduction ranged widely from 1% using only voluntary restrictions to 49% with the most stringent water restrictions.

3.5.6 Virginia

In response to drought conditions in 2002, the State of Virginia created a drought assessment and response plan designed to monitor drought conditions across the state. The plan also gave the Deputy of Natural Resources the responsibility of implementing water use restrictions. The responsibility of monitoring drought conditions is held by the Virginia Drought Monitoring Task Force (DMTF). The DMTF uses four indicators: precipitation, stream flows, ground water levels, and surface water levels to provide drought stage recommendations to the Virginia Drought Coordinator. Three drought stages are identified in the State's plan including Drought Watch, Drought Warning and Drought Emergency. Due the variable impacts of drought on different types of supply sources, the response activities implemented during each drought stage are tailored to the specific drought conditions. The plan does, however, identify reduction targets of 5% during Stage 1, 5% - 10% during Stage 2 and 10-15% during Stage 3.

A study of the 2002 drought in Virginia focused on the effectiveness of drought management programs and the impact of the intensity at which the programs were implemented. The study used data from 21 water suppliers including cities and counties and highlighted the difficulty in determining the intensity level of different management programs. The study concluded that strong enforcement of restrictions was vital to achieving desired levels of demand reduction. The following conclusions were presented by the study:

- Voluntary restrictions resulted in demand reductions ranging from 0% to 7%
- Mandatory restrictions resulted in demand reductions ranging from 4% to 22%
- Magnitude of reductions increased as information and enforcement increased
- Mandatory measures were in place mostly during winter months. The demand reductions would likely be higher than reported above if the mandatory measures were in place during summer months when outdoor water use is typically higher.

3.6 Commonly used Drought Contingency Measures and the Associated Savings

Drought contingency plans are commonly organized as a matrix of drought stages varying from a "watch or "warning" to "severe" or "emergency" drought conditions. Demand reduction goals are often described as a percentage and increase as the level of drought intensifies. These goals are usually set based on some level of risk analysis, which considers the drought susceptibility of the supply source and the importance of the source to the health and safety of the community. Drought contingency plans from Region H and nationally, were analyzed to develop stage reduction goals for a hypothetical typical drought contingency plan that could be used to analyze the effects of demand management measures on surface water reservoirs within Region H. Table 1, lists the stage reduction goals for some of the drought contingency plans studied during this analysis.

Stage I reductions are typically between 0% 10%. Most agencies implement education strategies during the early stages of their drought plans and may also request voluntary reductions. The City of Houston for example, implements education strategies and reduces water use by city departments by 10%. The South Florida Water Management District has issued advisory notices in the past asking users for voluntary reductions starting the public education process prior to implementing mandatory restrictions; no demand reduction goal is associated with the education measure.

Stage II typically involves increasing voluntary reductions through improving public awareness and may impose mandatory reductions on some types of use. The first phase outlined in the South Florida Water Management District's plan is included under Stage II because it imposes mandatory restrictions on outdoor watering. The City of Houston's plan sets a demand reduction goal of 15% to be achieved through increased voluntary reductions as a result of public awareness.

Stage III demand reductions ranged from 15% to 50% depending on the level of mandatory restrictions placed on water use and the limitations on aesthetic water use. The highest restrictions were found in Denver, Colorado where reservoir supplies are highly susceptible to drought conditions which reduces the winter snow pack used to fill their reservoirs. In less drought susceptible climates, the level of mandatory restrictions typically include time of day watering and various prohibitions on wasting water to achieve demand reductions of around 15% - 20%.

Stage IV water restrictions typically included continuing restrictions from Stage III and placing additional bans on non-essential water use including recreational and aesthetic usages. During severe droughts, provisions are often in place to provide pro-rata curtailments to contracted customers which can further increase the demand reduction goals.

Table 1. Summary of Water Demand Reduction

Drought Contingency Stage	Entity	Demand Reduction Target	Drought Contingency Stage	Entity	Demand Reduction Target
Stage I	City of Houston, TX	10%	Stage II	City of Houston, TX	10%
	Galveston, TX	0%		Galveston, TX	10%
	Santa Barbara, CA	10%		San Diego, CA	20%
	Peoria, AZ	5%		Peoria, AZ	10%
	South Florida Water Management District (SFWMD), FL	0%		South Florida Water Management District (SFWMD), FL	15%
	Denver, CO	10%		Denver, CO	30%
Stage III	City of Houston, TX	15%	Stage IV	City of Houston, TX	20%
	Galveston, TX	10%		Galveston, TX	20%
	San Diego, CA	40%		San Diego, CA	>40%
	Peoria, AZ	15%		Peoria, AZ	TBD
	South Florida Water Management District (SFWMD), FL	30%		South Florida Water Management District (SFWMD), FL	45%
	Denver, CO	50%		Denver, CO	66%

Demand management measures that may be used to achieve specific demand reduction goals are outlined for each drought stage. The goals outlined by individual drought plans can vary widely based on the hydrology of the region and the specific demographics of the end water users. A hypothetical typical drought plan was developed to model the effects of drought management measures on surface water reservoirs in Region H. The drought plan was divided into four stages with target demand reductions for each stage. Specific drought management measures are listed for each Stage.

Table 2. Hypothetical Typical Drought Plan

Stage 1 – Mild Drought Conditions (5% Demand Reduction)

- Initiate Public Information Campaign
- Request that Customers Limit Outdoor Irrigation
- Request that Customers Investigate and Repair Leaks
- Request Major Customers to make Voluntary Reductions in Water Use
- Reduce Water Use in Public Departments

Stage 2 – Moderate Drought Conditions (10% Demand Reduction)

- Increase Public Information Campaign
- Restrict Outdoor Watering to Specific Hours and Days
- Prohibit the Planting of New Lawns
- Provide Water Audits for Large Irrigated Public Areas
- Increase Leak Detection and Repair Activities
- Increase Reduction of Water Use in Public Departments
- Prohibit Washing of Non-commercial Vehicles and Impervious Areas
- Prohibit Filling of Private Swimming Pools

Stage 3 – Severe Drought Conditions (20% Demand Reduction)

- Continue Stage 2 Measures
- Increase media involvement
- Increase Outdoor Watering Restrictions
- Impose penalties on Water Waste, Permit Violations and for Noncompliance with Restrictions
- Ban Aesthetic Water Use
- Restrict Restaurants from Serving Water unless Requested by Customers.
- Increase Rates to Increase Financial Incentives for using Less Water
- Impose a Moratorium on New Connections

Stage 4 – Severe Drought Conditions (30% Demand Reduction)

- Continue Stage 3 Measures
- Eliminate all Fire Hydrant Uses Outside of those Required for Public Health and Safety
- Prohibit all Indoor and Outdoor Aesthetic Water Use.
- Prohibit Non Essential Water Use
- Reduce Water Service to Customers

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Section 4 – Evaluation of Water Supply Reservoirs in Absence of Drought Management Measures

The effects of projected demands on lake levels during the drought of record were analyzed with and without drought management measures. To perform the analysis, the TCEQ WAM was updated with year 2000 and 2060 area capacity curves to reflect the effects of sedimentation on reservoir storage. The reservoirs were modeled under several scenarios to prepare a base line from which the effects of various drought contingency plans could be measured. The scenarios used in the analysis included Run 8 (current levels of water diversions and return flows), Run 3 (full authorized diversions and 100% reuse) and Liv60rf (a Run 3 model with full authorized diversions, modified by the addition of expected return flows from Region C) to model the expected conditions for Lake Livingston. Runs 3 & 8 were simulated with the year 2000 and 2060 area capacity curves for Lake Livingston, Conroe and Houston. Lake Livingston was also simulated using Run Liv60rf with the year 2060 area capacity curves. The future Allens Creek Reservoir was modeled using Runs 3 & 8 with the permitted area capacity curve already present in the models.

The results of the simulations in the absence of drought management measures are summarized in the following sections. The simulated reservoir surface water elevations for each base line run are presented on separate figures for the year 2000 and year 2060 area capacity curves. Surface water elevations for Allens Creek are presented on a single graph using the permitted area capacity curve. The base runs for each reservoir are also presented in a percentile comparison in the appendices for each reservoir. The percentile values record what percentage of time the reservoir elevation is less than or equal to the value listed in the table. For Allens Creek, the data is reported as reservoir storage in acre-ft.

4.1 Lake Livingston

Figure 4-1. Lake Livingston Elevations, Year 2000 Storage Capacity

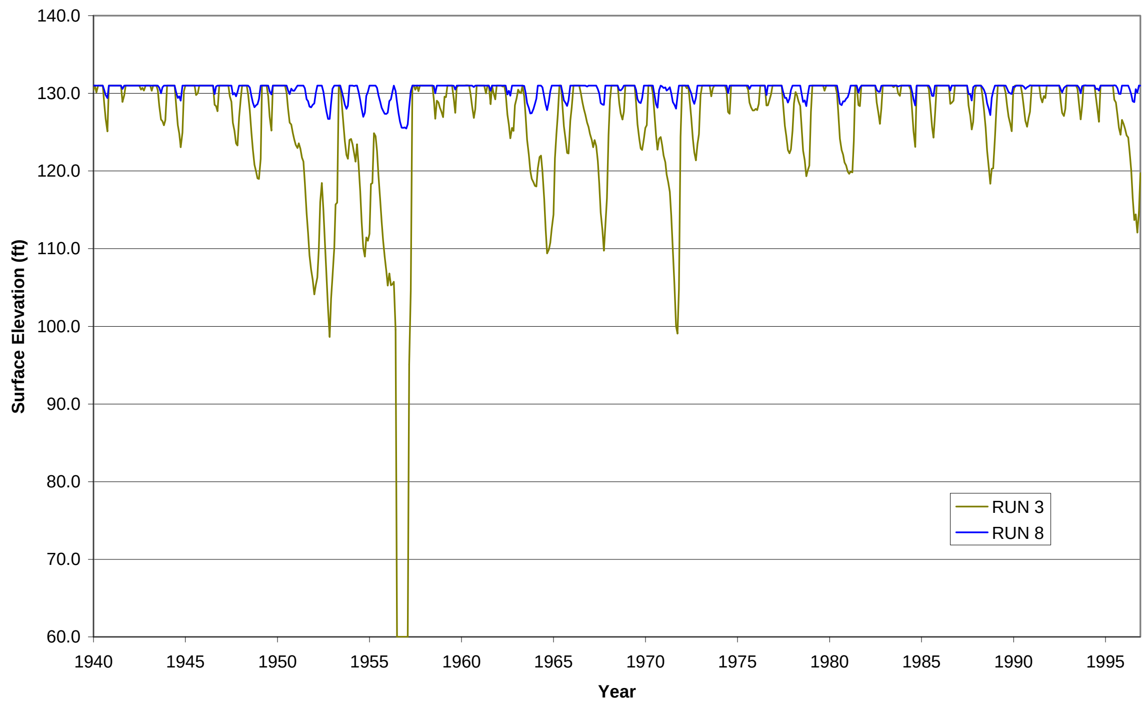
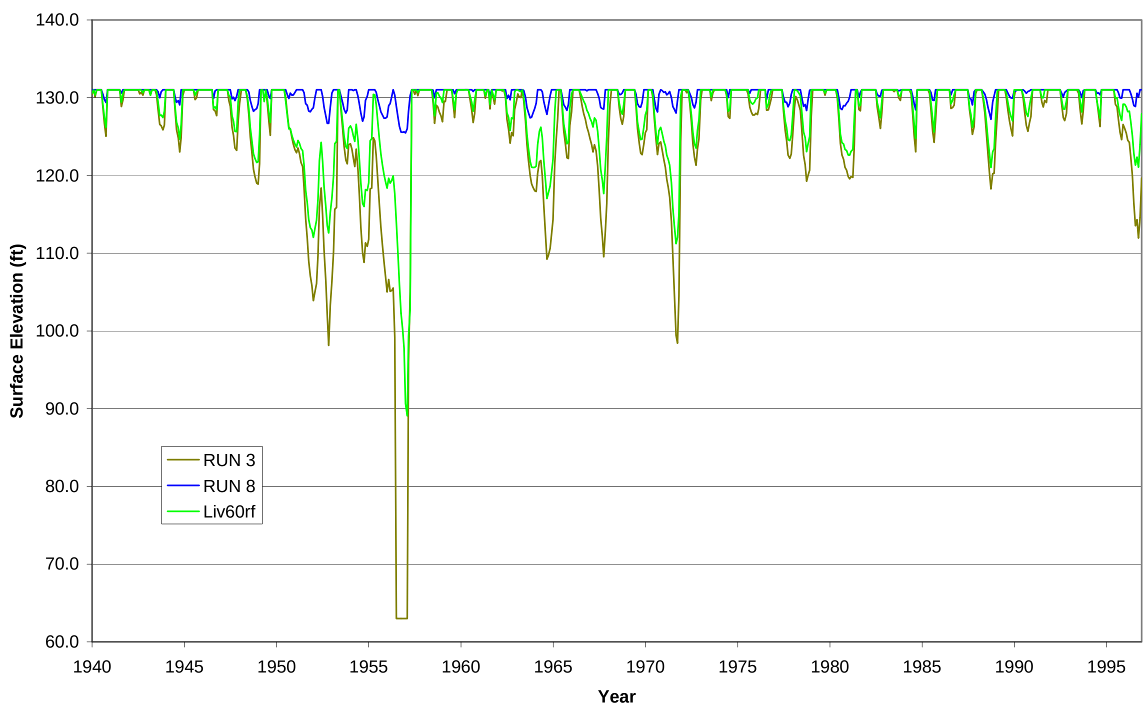


Figure 4-2. Lake Livingston Elevations, Year 2060 Storage Capacity



As can be seen on Figure 4-2, Lake Livingston is dependant on return flows from Region C. Using the TCEQ Run 3, which simulates full authorized diversions without return flows, the lake level would reach the minimum elevation (approximately 60 ft in the year 2000 and 62 ft in the year 2060) under drought of record conditions. Using the TCEQ Run 8 model, which simulates current levels of diversions and return flows, the lake is full almost 75% of the time with a minimum elevation of approximately 125 ft. The expected scenario for Lake Livingston includes return flows from Region C and is simulated by the Liv60rf model. The model was adopted to represent the year 2060 firm yield scenario for Lake Livingston in the 2006 Region H Water Plan and is essentially an updated Run 3 model which includes the expected return flows from Region C. Using the Liv60rf model, Lake Livingston remained full nearly 50% of the time and reached a minimum elevation of approximately 90.5 ft.

4.2 Lake Conroe

Figure 4-3. Lake Conroe Elevation, Year 2000 Storage Capacity

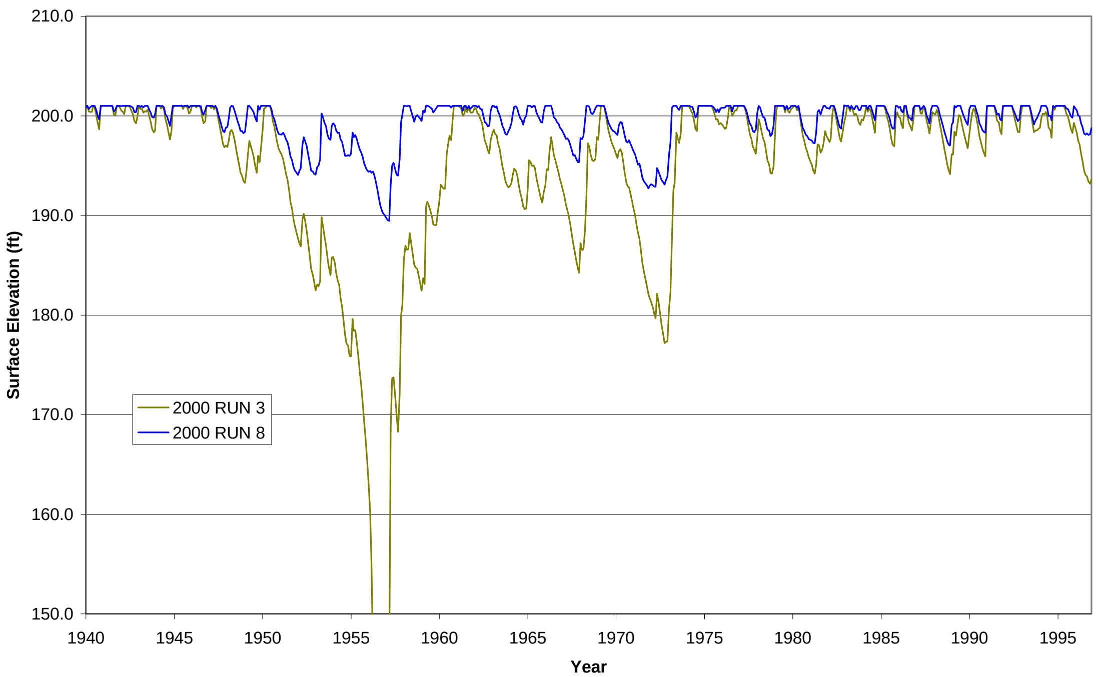
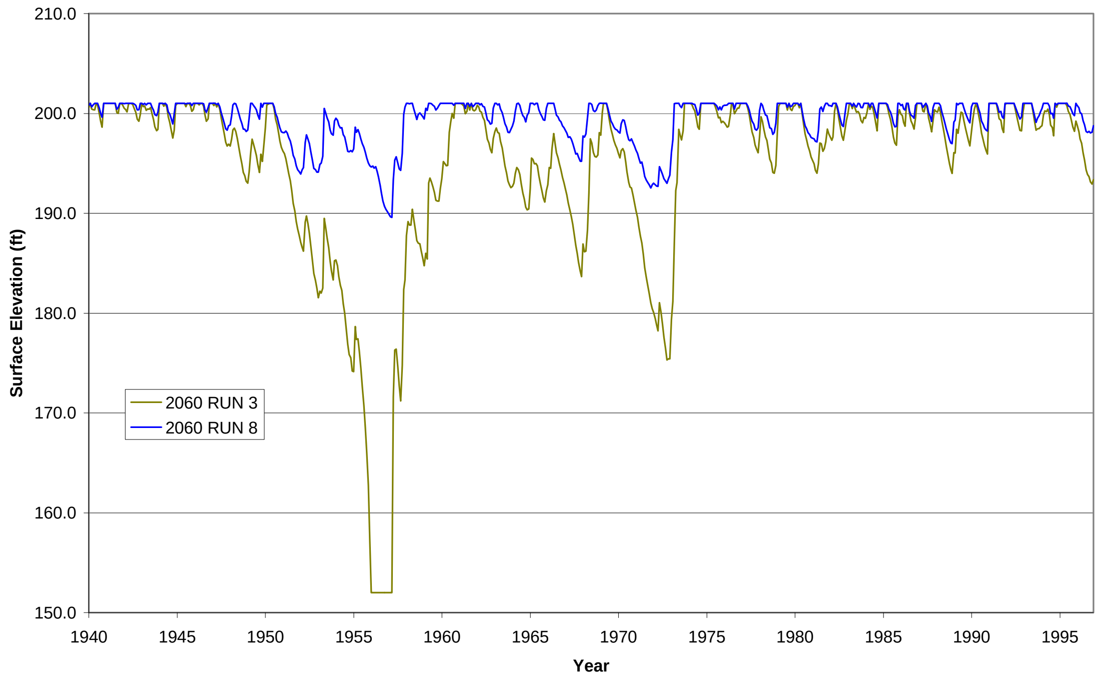


Figure 4-4. Lake Conroe Elevations, Year 2060 Storage Capacity



Using the Run 8, current conditions model, the water surface level of Lake Conroe varies from elevation 201 ft to 150 ft, approximately an 11 ft variation. Discussions with the San Jacinto River Authority (SJRA) revealed that the diversions simulated in the Run 8 model totaled approximately 47,000 acre-ft and included a "one-time" release from Lake Conroe to Lake Houston. This "one-time" release was included in the Run 8 model as an annual diversion target totaling 31,293 acre-ft per year. As a result, the current Run 8 model does not accurately reflect the "current conditions" on Lake Conroe but can still be utilized in this study to evaluate the effectiveness of various drought contingency plans.

Results from the Run 3 simulation show the level of Lake Conroe reaching the minimum elevation during drought of record conditions. Using the year 2000 area capacity curve the water surface elevation reaches a minimum level of approximately 145 ft. Updating the Run 3 model with the 2060 area capacity curve raises the lake bottom elevation to 152 ft to account for sedimentation. Under Run 3 conditions the lake remains full over 40% of the time.

4.3 Lake Houston

Figure 4-5. Lake Houston Elevations, Year 2000 Storage Capacity

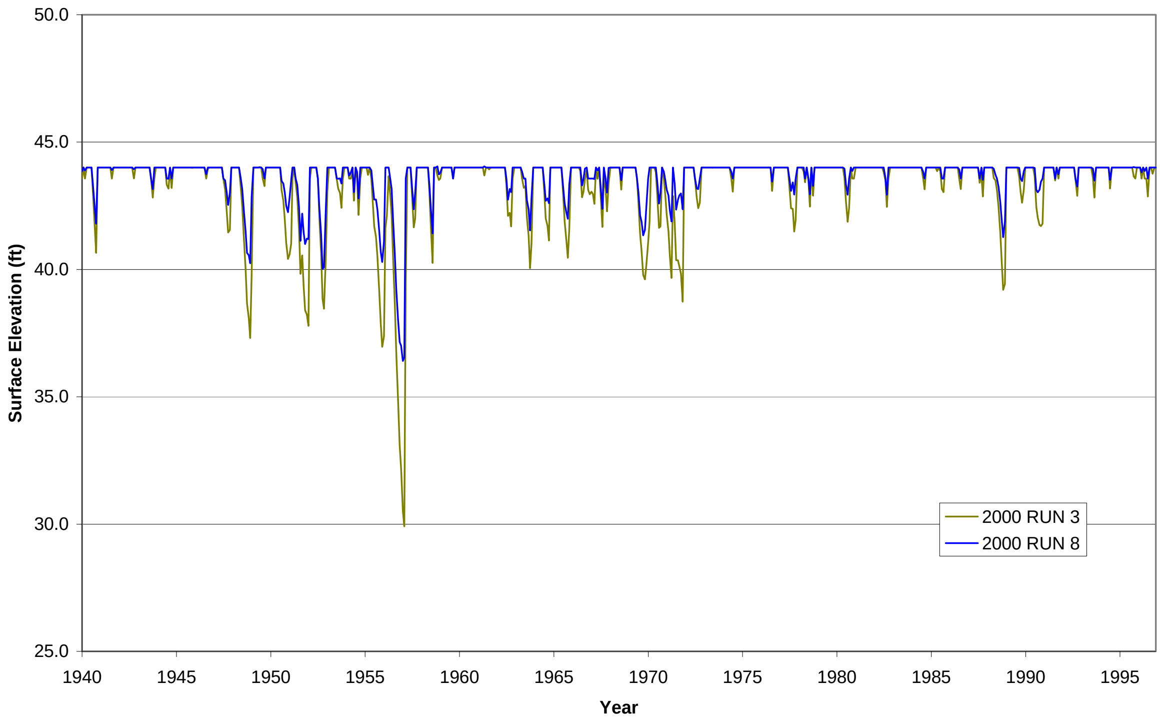
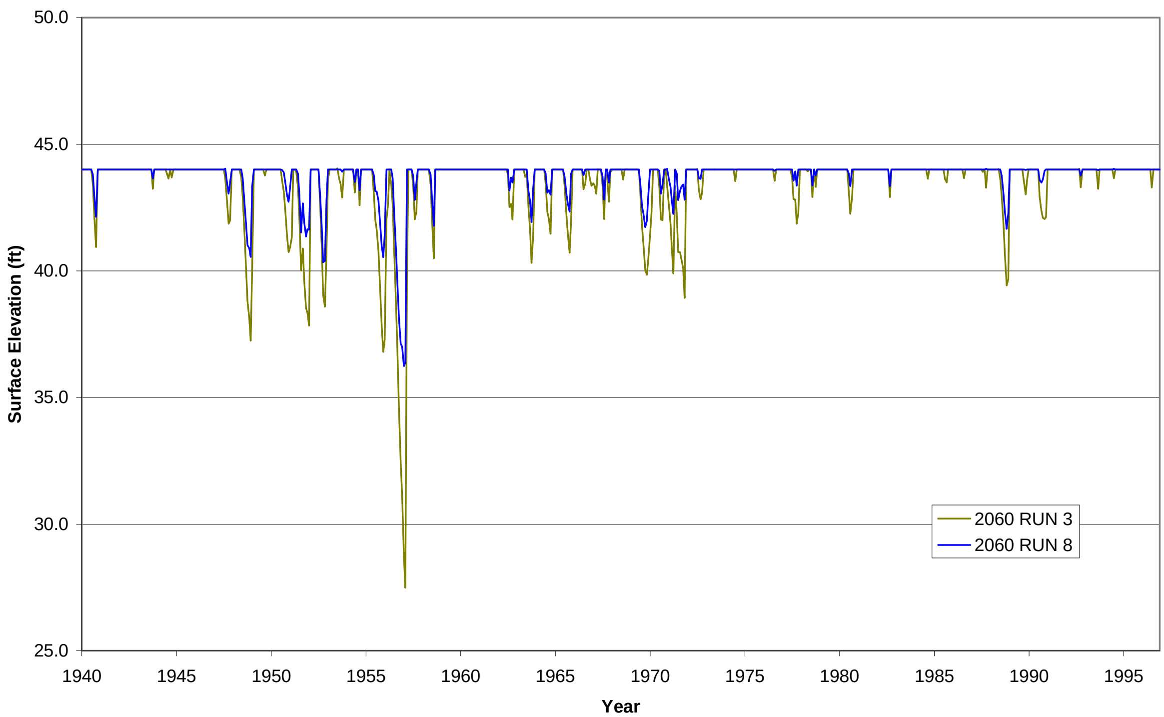


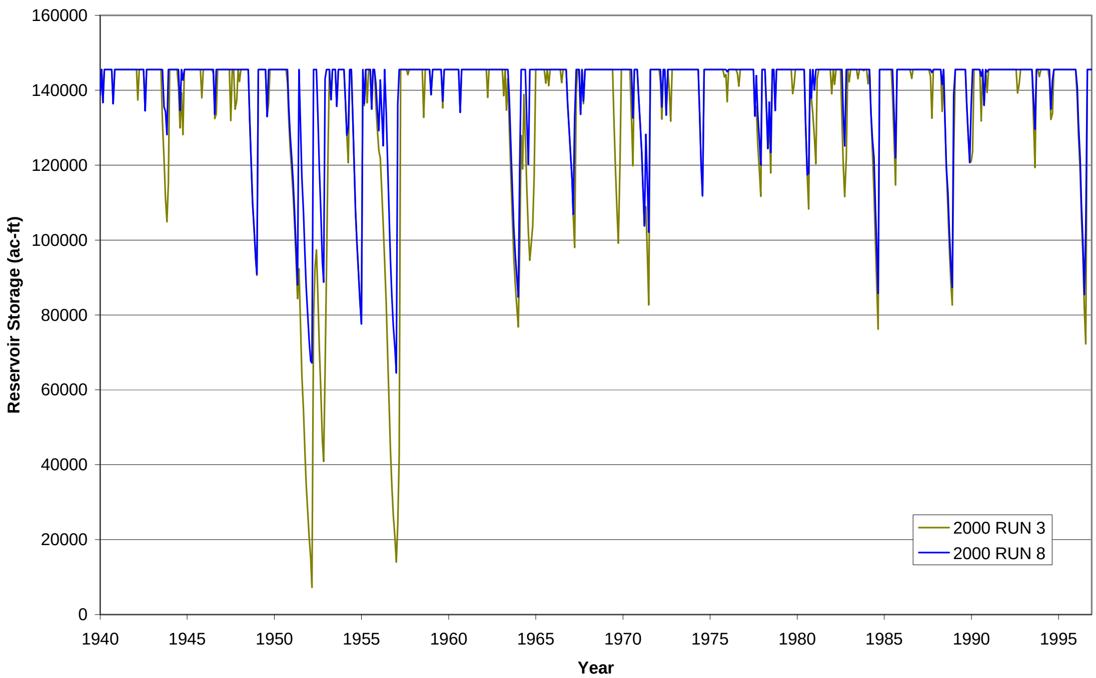
Figure 4-6. Lake Houston Elevations, Year 2060 Storage Capacity



Due to its downstream location and senior priority, Lake Houston is able to capture inflows from a large drainage area and can require Lake Conroe to pass inflows downstream until Lake Houston can satisfy its diversions. As a result, full use of water rights and drought conditions has a less severe impact on lake levels. Lake Houston remains full approximately 65% percent of the time using the Run 3 scenario. Using the TCEQ Run 8, Lake Houston is full almost 75% of the time, only a slight increase over the Run 3 scenario. Water surface levels in Lake Houston vary approximately 7.5 ft using the TCEQ Run 8 model and approximately 14 ft using Run 3.

4.4 Allens Creek Reservoir

Figure 4-7. Allens Creek Storage, Full Permitted Capacity



Allens Creek was modeled using the full permitted storage capacity described in the TCEQ Run 3 model. As a permitted future reservoir, Allen Creek, does not have a final stage-capacity curve that can be used to translate reservoir volume into elevations. Therefore, the discussion of drought contingency plan impacts on the reservoir will focus on storage levels instead of elevations.

The storage in Allens Creek varies from 145,533 acre-ft at full capacity to a minimum of 7,237 acre-ft during drought of record conditions using Run 3 and 64,457 acre-ft using Run 8. The reservoir remained at full capacity over 50% of the time in the Run 3 simulation and 75% of the time in the Run 8 simulation. The Run 8 model was modified to include Allens Creek with full permitted diversion and the full permitted storage capacity. While it is unlikely this scenario will represent current conditions at the time when the future reservoir is constructed, it provides a reasonable “current conditions” scenario to compare the effects of various drought contingency plans.

Section 5 – Evaluation of Water Supply Reservoirs with Drought Management Measures

The effects of drought contingency plans on lake levels during the drought of record were analyzed with existing agency drought contingency plans and a hypothetical typical drought contingency plan outlined in section 3.6. To perform the analysis, the TCEQ WAM was updated to include the effects of implementing the drought contingency plans as a percentage reduction in the municipal diversions made from the reservoirs. The reservoirs were modeled under several scenarios to evaluate different drought contingency plan impacts using various demands and return flows. The scenarios used in the analysis included Run 8 (current levels of water diversions and return flows), Run 3 (full authorized diversions and 100% reuse) and Liv60rf (full authorized diversions, with expected return flows from Region C) to model the most likely scenario for Lake Livingston. Run 8 used the year 2000 sedimentation condition to simulate the lake levels under "existing" conditions, runs Liv60rf & Run 3 were performed with the year 2060 sedimentation conditions to simulate an "ultimate" condition for year 2060.

Comparisons of lake levels and storage with and without drought management measures are summarized in the following sections. Modeling drought management measures resulted in an increase in the minimum volume of water stored in the reservoirs during the drought of record. This increase in storage volume was compared to the results presented in Section 4 and is presented in this section as the number of months of remaining supply. Additional tables and graphs further detailing the effects of each drought contingency plan during the drought of record are provided in Appendices A – D. The following sections also present the different triggers and demand reductions used to simulate the existing agency drought contingency plan and the typical plan. Each drought contingency plan was simulated using two different variations identified as "CASE 1" and "CASE 2". The two assumed DCP variations are identified below:

- "CASE 1" assumes that the drought management measures are only implemented during the summer months May – September. These summer months represent peak water usage with increased outdoor and recreational water use. Historically, drought contingency plans in Region H have most often been implemented during these summer months when peak demands encroach on the maximum pumping capacity stressing distribution systems.
- "CASE 2" assumes that the drought management measures are effective during the summer months May – September. This variation also assumes that the drought management measures have some effectiveness during the off peak (winter) months October – April when outdoor and recreational water use have declined. For example, under a Stage 3 drought warning, a 20% demand reduction is achieved during summer months and a 10% demand reduction is achieved during winter months. The variation assumes that half of peak demand reduction percentage is achievable during the off peak months.

5.1 Lake Livingston

Effects of drought contingency plans on Lake Livingston were modeled using the existing TRA drought contingency plan and a drought contingency plan typical of other major water providers. The existing TRA drought contingency plan implements stages of the drought contingency plan when the water surface elevation of Lake Livingston is below the Elevations listed below in Table 3. The typical drought contingency plan shown below triggers stages in the drought contingency plan based on a percentage of the reservoir storage. The demand reductions listed for both drought contingency plans were applied to municipal diversions from Lake Livingston.

Table 3. Lake Livingston DCPs

	TRA DCP		Typical DCP	
Stage	Elevation (ft)	Demand Reduction	Reservoir Storage (acre-ft)	Demand Reduction
1	126.50	5%	70%	5%
2	124.00	15%	60%	10%
3	121.40	25%	50%	20%
4	-	-	40%	30%

The drought contingency plans listed above were simulated using both the TCEQ WAM Run 8 to simulate current conditions and with the Liv60rf model to simulate full diversions and expected return flows. Each drought contingency plan was modeled with two variations described as “CASE 1” and “CASE 2”. The impact of the drought contingency plans was evaluated based on the minimum storage in the reservoir during the drought of record. The minimum storage level was used to determine the number of months that the reservoir supplies could continue to meet demands if the drought of record continued. Table 4 below summarizes the Region H supplies from Lake Livingston projected in the 2006 Region H Water Plan. Tables 5 and 6 identify the number of months that the supplies could continue to be met if the drought conditions continued past the drought of record. The minimum storage volume identified from the WAM output was divided by the projected demands to estimate the months of remaining supply. Appendix A contains graphical results of lake during the simulation period and the drought of record.

Table 4. Livingston Projected Demands

Year	Demand (AFY)
2000	745,617
2010	820,020
2020	966,102
2030	1,068,845
2040	1,120,753
2050	1,215,812
2060	1,258,245

Table 5. Months of Supply Remaining (RUN 8)

RUN 8 – Current Diversions, Current Level of Return Flows

Year	RUN 8	TRADCP CASE 1	TRADCP CASE 2	TYPDCP CASE 1	TYPDCP CASE 2
2000	21.1	21.1	21.1	21.1	21.1
2010	19.2	19.2	19.2	19.2	19.2
2020	16.3	16.3	16.3	16.3	16.3
2030	14.7	14.7	14.7	14.7	14.7
2040	14.1	14.1	14.1	14.1	14.1
2050	13.0	13.0	13.0	13.0	13.0

2060	12.5	12.5	12.5	12.5	12.5

Table 6. Months of Supply Remaining (Liv60rf)

Liv60rf – Full Authorized Diversions, Expected Return Flows

Year	Liv60rf	TRADCP CASE 1	TRADCP CASE 2	TYPDCP CASE 1	TYPDCP CASE 2
2000	0.5	2.9	4.1	2.1	3.3
2010	0.5	2.7	3.8	1.9	3.0
2020	0.4	2.3	3.2	1.6	2.6
2030	0.4	2.0	2.9	1.5	2.3
2040	0.3	1.9	2.8	1.4	2.2
2050	0.3	1.8	2.5	1.3	2.0
2060	0.3	1.7	2.5	1.3	2.0

The tables above quantify the number of months the reservoir minimum storage could continue to meet demands if drought conditions continued past the drought of record. Using the TCEQ Run 8 model, the minimum storage in Lake Livingston during the drought of record was approximately 1,303,300 acre-ft which would allow the lake to continue to supply demands for approximately 19.2 months in 2010 during drought conditions decreasing to 12.5 months in 2060. The drought contingency plans have little to no effect on Lake Livingston in the current conditions model because lake levels are consistently above Stage 1 triggers. Using the Liv60rf model, without drought management measures, Lake Livingston could continue to meet demands for less than 1 month in the year 2060. Implementing the existing TRA drought contingency plan increases the months of supply to 1.7 and 2.5 using CASE 1 and CASE 2 assumptions, respectively. The typical drought contingency plan increases the months of supply to 1.3 and 2.0 months using CASE 1 and CASE 2, respectively. The number of months the reservoir could continue to meet demands is presented in percentile tables in appendix A.

In the year 2060 approximately 39,075 afy are projected to be supplied from Lake Livingston to meet irrigation demands in Region H. An additional analysis was performed to analyze the effects of implementing a “dry year option” to curtail irrigation diversion form Lake Livingston during stage 3 and 4 of the typical drought plan. The “TYPDCP CASE 2” scenario was updated to include a 25% year-round curtailment of irrigation diversions during stage 3 drought conditions and a 50% curtailment during stage 4. The dry year option was implemented in addition to the municipal demand reductions prescribed in the typical drought contingency plan scenario. The effects of the dry year option scenario (DRYDCP) are presented below. The addition of irrigation curtailments during stage 3 and 4 of the drought plan had little effect on the minimum reservoir storage volume. The volume increased from 205,400 acre-ft in the typical drought plan scenario (TYPDCP CASE 2) to 213,600 acre-ft with additional irrigation curtailments (DRYDCP). Similarly, the months of supply available in the lake was not significantly increased.

Table 7. Dry Year Option

Liv60rf – Full Authorized Diversions, Expected Return Flows

Scenario	Minimum Storage (acre-ft)	Months of Supply Remaining
Liv60rf	31,900	0.3
TYPDCP CASE 2	205,400	2.0
DRYDCP	213,600	2.04

5.2 Lake Conroe

Effects of drought contingency plans on Lake Conroe were modeled using the existing SJRA drought contingency plan and a typical drought contingency plan. The existing SJRA drought contingency plan implements stages of the drought contingency plan when the water surface elevation of Lake Conroe is below the elevations listed below in Table 8. The typical drought contingency plan triggers stages in the drought contingency plan based on a percentage of the reservoir storage. The demand reductions listed for both drought contingency plans were applied to the municipal diversions from Lake Conroe.

Table 8. Lake Conroe DCPs

	SJRA DCP		Typical DCP	
Stage	Elevation (ft)	Demand Reduction	Reservoir Storage (acre-ft)	Demand Reduction
1	194.00	10%	70%	5%
2	190.00	15%	60%	10%
3	185.00	20%	50%	20%
4	-	-	40%	30%

The drought contingency plans listed above were simulated using both the TCEQ WAM RUN 8 to simulate current conditions and with the TCEQ WAM RUN 3 model to simulate full authorized diversions without return flows. Each drought contingency plan was modeled with two variations described as “CASE 1” and “CASE 2”. The impact of the drought contingency plans was evaluated based on the minimum storage in the reservoir during the drought of record. The minimum storage level was used to determine the number of months that the reservoir supplies could continue to meet demands if the drought of record continued. Table 9 below summarizes the Region H supplies from Lake Conroe projected in the 2006 Region H Water Plan. Tables 10 and 11 identify the number of months that the supplies could continue to be met if the drought conditions continued past the drought of record. The minimum storage volume identified from the WAM output was divided by the projected demands to estimate the months of remaining supply. Appendix B contains graphical results of the lake levels during the simulation period and the drought of record.

Table 9. Lake Conroe Projected Demands

Year	Demand (AFY)
2000	20,745
2010	28,488
2020	73,001
2030	74,255
2040	74,300
2050	74,300
2060	74,300

Table 10. Months of Supply Remaining (RUN 8)

RUN 8 – Current Diversions, Current Level of Return Flows

Year	RUN 8	SJRADCP CASE 1	SJRADCP CASE 2	TYPDCP CASE 1	TYPDCP CASE 2
2000	130.9	132.0	132.4	131.5	132.0
2010	95.3	96.1	96.4	95.8	96.1
2020	37.2	37.5	37.6	37.4	37.5
2030	36.6	36.9	37.0	36.7	36.9
2040	36.5	36.8	37.0	36.7	36.8
2050	36.5	36.8	37.0	36.7	36.8
2060	36.5	36.8	37.0	36.7	36.8

Table 11. Months without Reservoir Storage – No Diversions (RUN 3)

RUN 3 – Full Authorized Diversions, No Return Flows

	RUN 3	SJRADCP CASE 1	SJRADCP CASE 2	TYPDCP CASE 1	TYPDCP CASE 2
Months	15	13	11	12	10

The tables above quantify the number of months the reservoir minimum storage could continue to meet demands if drought conditions continued past the drought of record. Using the Run 8 model the minimum storage during the drought of record of approximately 226,300 acre-ft. The Run 8 minimum storage volume could continue to meet annual diversions of 28,488 acre-ft per year in 2010 for almost 8 years. This result does not accurately reflect the current conditions on Lake Conroe however. The Run 8 model shows a 47,000 annual diversion from Lake Conroe that was based on a “one-time” release and not on a current annual diversion. Using the Run 3 model, without drought management measures, Lake Conroe would be unable to supply diversions for approximately 15 months. Implementing the existing SJRA drought contingency plan on all municipal diversions from the lake decreases the months that the lake is unable to meet supplies to 13 and 11 using CASE 1 and CASE 2 assumptions respectively. The typical drought contingency plan would further reduce the shortage period to 12 and 10 months using CASE 1 and CASE 2 respectively. The number of months the reservoir could continue to meet demands is presented in percentile tables in appendix B.

An additional analysis was performed to determine the level of demand reductions that would be necessary to prevent the reservoir from going dry and provide a constant level of diversion during drought years. The base Run 3 model updated with the 2060 area-capacity storage curve was used as the base for the analysis. In the model 66,000 afy is diverted with a municipal diversion pattern and 34,000 afy was diverted with an industrial pattern. For the analysis it was assumed that the Case 2 seasonal reduction pattern was applied to the 66,000 afy municipal diversions and a year-round reduction was applied to the 34,000 industrial demands. The stage and reduction goals that prevented the lake from going dry during the drought of record are presented below. Graphs showing the impact of the hypothetical drought plan are presented in Appendix B.

Table 12. Hypothetical DCP Reduction Goals

Drought Stage	Reduction Goal
Municipal: 66,000 afy	
1	15%
2	25%
3	35%
4	45%
Industrial: 34,000 afy	
1	15%
2	25%
3	35%
4	45%

5.3 Lake Houston

Effects of drought contingency plans on Lake Houston were modeled using a typical drought contingency plan. The typical drought contingency plan shown below triggers drought stages based on a percentage of the reservoir storage. The demand reductions listed below were applied to municipal diversions from Lake Houston.

Table 13. Lake Houston DCPs

Typical DCP		
Stage	Reservoir Storage (acre-ft)	Demand Reduction
1	70%	5%
2	60%	10%
3	50%	20%
4	40%	30%

The drought contingency plans listed above were simulated using both the TCEQ WAM Run 8 to simulate current conditions and with the TCEQ WAM Run 3 model to simulate full authorized diversions without return flows. Each drought contingency plan was modeled with two variations described as “CASE 1” and “CASE 2”. The impact of the drought contingency plans was evaluated based on the minimum storage in the reservoir during the drought of record. The minimum storage level was used to determine the number of months that the reservoir supplies could continue to meet demands if the drought of record continued. Table 14 below summarizes the Region H supplies from Lake Houston projected in the 2006 Region H Water Plan. Tables 15 and 16 identify the number of months that the supplies could continue to be met if the drought conditions continued past the drought of record. The minimum storage volume identified from the WAM output was divided by the projected demands to estimate the months of remaining supply. Appendix C contains graphical results of the lake levels during the simulation period and the drought of record.

Table 14. Lake Houston Projected Demands

Year	Demand (AFY)
2000	105,173

Year	Demand (AFY)
2010	160,324
2020	168,000
2030	168,000
2040	168,000
2050	168,000
2060	168,000

Table 15. Months of Supply Remaining (RUN 8)

RUN 8 – Current Diversions, Current Level of Return Flows

Year	RUN 8	TYPDCP CASE 1	TYPDCP CASE 2
2000	6.6	6.7	7.0
2010	4.3	4.4	4.6
2020	4.1	4.2	4.4
2030	4.1	4.2	4.4
2040	4.1	4.2	4.4
2050	4.1	4.2	4.4
2060	4.1	4.2	4.4

Table 16. Months of Supply Remaining (RUN 3)

RUN 3 – Full Authorized Diversions, No Return Flows

Year	RUN 3	TYPDCP CASE 1	TYPDCP CASE 2
2000	0.7	0.7	1.4
2010	0.4	0.5	0.9
2020	0.4	0.4	0.9
2030	0.4	0.4	0.9
2040	0.4	0.4	0.9
2050	0.4	0.4	0.9
2060	0.4	0.4	0.9

The tables above quantify the number of months the reservoir minimum storage could continue to meet demands if drought conditions continued past the drought of record. Using the Run 3 model, without drought management measures, Lake Houston could continue to meet demands for less than 1 month. Implementing the typical drought contingency plan increases the number of months from .4 to .9 using CASE 2, which assumes that demands can be effectively reduced during winter months when outdoor water use and recreational use is historically lower. Using Run 8 the minimum storage in Lake Houston during the drought of record was approximately 58,000 acre-ft. The reservoir storage could continue to meet the annual diversion for approximately less than 5 months. The number of months the reservoir could continue to meet demands is presented in percentile tables in appendix C.

5.4 Allens Creek Reservoir

Effects of drought contingency plans on the proposed Allens Creek Reservoir were modeled using the existing BRA drought contingency plan and a typical drought contingency plan. The existing BRA drought contingency plan set trigger elevations based on reservoir occurrence frequencies. The typical drought contingency plan shown below triggers drought stages based on a percentage of the reservoir storage. The demand reductions listed for the typical drought contingency plan were applied to the municipal diversions from the Allens Creek Reservoir.

Table 17. Allens Creek DCPs

	BRA DCP		Typical DCP	
Stage	Occurrence Frequency	Demand Reduction	Reservoir Storage (acre-ft)	Demand Reduction
1	20%	-	70%	5%
2	10%	3	60%	10%
3	5%	7	50%	20%
4	-	-	40%	30%

The drought contingency plans listed above were simulated using the TCEQ WAM Run 3 model to simulate full authorized diversions without return flows. Each drought contingency plan was modeled with two variations described as “CASE 1” and “CASE2”. The impact of the drought contingency plans was evaluated based on the minimum storage in the reservoir during the drought of record. The minimum storage level was used to determine the number of months that the reservoir supplies could continue to meet demands if the drought of record continued. Table 18 below summarizes the Region H supplies from the Allens Creek Reservoir projected in the 2006 Region H Water Plan. Table 19 identifies the number of months that the supplies could continue to be met if the drought conditions continued past the drought of record. The minimum storage volume identified from the WAM output was divided by the projected demands to estimate the months of remaining supply. Appendix D contains graphical results of the lake levels during the simulation period and the drought of record.

Table 18. Allens Creek Projected Demand

Year	Demand (AFY)
2000	0
2010	0
2020	0
2030	97,410
2040	97,410
2050	97,410
2060	97,410

Table 19. Months of Supply Remaining (RUN 3)

RUN 3 – Full Authorized Diversions, No Return Flows

Year	RUN 3	BRADCP CASE 1	BRADCP CASE 2	TYPDCP CASE 1	TYPDCP CASE 2
2000	-	-	-	-	-
2010	-	-	-	-	-
2020	-	-	-	-	-
2030	0.9	1.4	1.6	1.6	2.1
2040	0.9	1.4	1.6	1.6	2.1
2050	0.9	1.4	1.6	1.6	2.1

2060	0.9	1.4	1.6	1.6	2.1

The table above quantifies the number of months the reservoir minimum storage could continue to meet demands if drought conditions continued past the drought of record. Using the Run 3 model, without drought management measures, Allens Creek could not continue to meet demands if the drought continued. Implementing the BRA drought contingency plan would allow the reservoir to continue to meet demands for 1.4 and 1.6 months using CASE 1 and CASE 2 assumptions respectively. The typical drought contingency plan would allow the reservoir to meet demands for 1.6 and 2.1 months using CASE 1 and CASE 2 respectively. The number of months the reservoir could continue to meet demands is presented in percentile table in the appendices.

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Section 6 – Projected Water Savings

Water use savings were projected for each WUG in Region H associated with the reservoirs evaluated in this study. Reduction estimates were the effects of the typical drought contingency plan on municipal diversions from surface water supply reservoirs. The impacts of drought management strategies on annual water demands are dependant on many factors including public perception, local demographics, type of restrictions, level of enforcement and the timing of drought stages. For instance, mandatory restrictions typically rely on limitations of outdoor and non-essential water use to reduce municipal water use. Such restrictions typically produce larger water use reductions when applied during summer months when outdoor and recreational water use it highest.

The duration of low surface water elevations has an impact on the duration that drought stages may be in effect and thus have an affect on the magnitude of demand reductions that can be achieved. Lake Conroe for example has a drought of record period that results in minimum lake elevations for a period of approximately 15 months. Lake Houston, on the other hand, has a drought period that lasts for approximately 1 year. Municipal demands on Lake Houston would be placed under stage 4 restrictions for a period of only six months using the typical drought contingency plan and will not realize the full annual demand reduction possible. As a result, the level of drought response is likely to vary between municipal users based on how susceptible their source of supply is during drought conditions. To reflect this, annual demand reductions (or water savings) were estimated for each reservoir based on implementing the typical drought contingency plan on municipal demands in response to drought of record conditions.

Table 20. Demand Reduction by Source during the Drought of Record

Source	Source_ID	Demand Reduction
Lake Livingston	084H0	20.88%
Lake Conroe	12900	24.86%
Lake Houston	10030	8.92%
Allens Creek	10060	14.57%

The estimated demand reductions listed above were then applied to Water User Groups (WUGs) in Region H with existing or projected use from the four surface water reservoirs to estimate the possible water savings associated with implementing demand-side management measures during drought of record conditions. For WUGs with supplies from multiple sources the water savings was estimated using a weighted average of the supplies. The resulting water savings associated with each WUG was then applied to the WUG total demand which included those portions that are projected to be met with other sources including ground water. When a municipality experiences drought conditions, drought management measures will be implemented on the entire demand. This is especially true in many large municipal systems which utilize both groundwater and surface water or have alternative water supplies. The resulting water demands projected during the drought of record (DOR Demand) for each WUG associated with the surface water reservoirs detailed in this study are provided in Appendix E.

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Section 7 – Impacts of Drought Management of Future Water Management Strategies

Implementation of drought management plans will have effects on annual water demands when implemented during drought conditions. Reduced demands during drought conditions however, does not allow water supplies to be reallocated to meet demands elsewhere. Unlike conservation strategies, water savings from drought management are only available during drought conditions. As a result, supplies offset by the projected water savings are not reliable and can not be reallocated to meet other demands. The additional annual supplies made available from each reservoir as a result of implementing DCP measures are illustrated in the following figures. Lake Livingston, Lake Houston and Allens Creek were modeled assuming the firm yield of the reservoirs. Lake Conroe was modeled assuming the full permitted capacity of 100,000 afy.

Figure 7-1. Additional Lake Livingston Supply

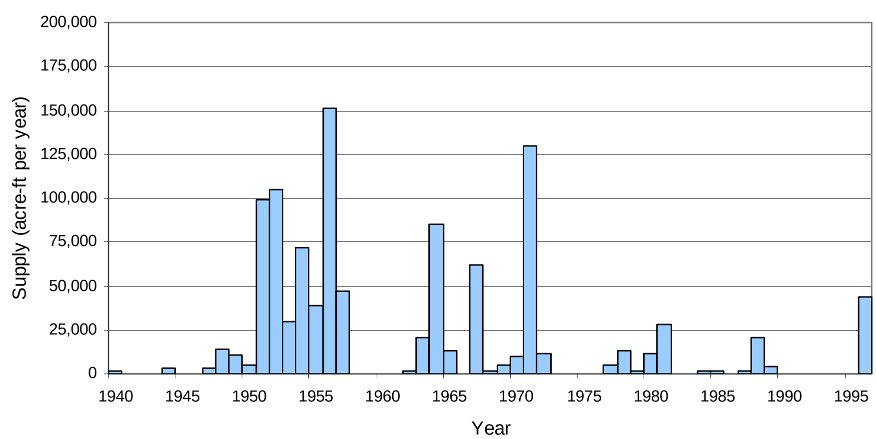


Figure 7-2. Additional Lake Conroe Supply

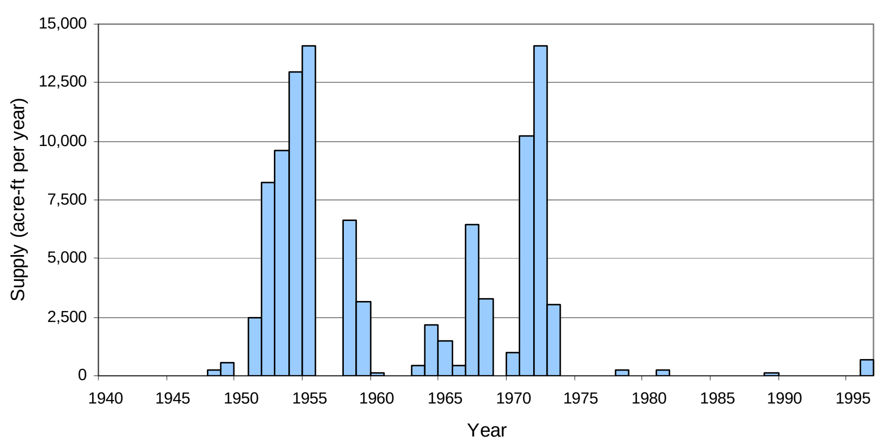


Figure 7-3. Additional Lake Houston Supply

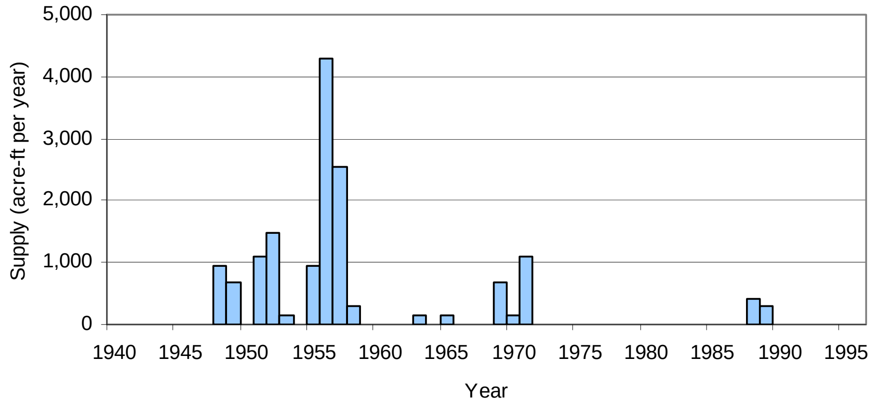
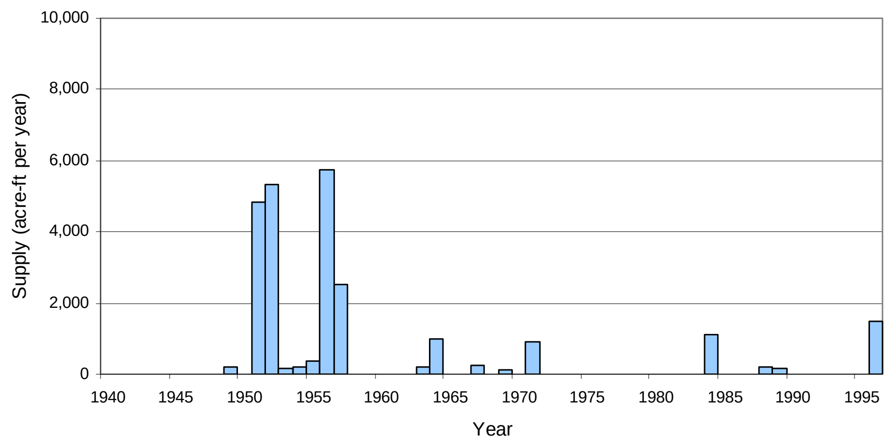


Figure 7-4. Additional Allens Creek Reservoir Supply



It is evident from the previous figures that additional supplies are only made available during drought conditions while drought management measures are in effect. The annual quantity of the additional supplies is dependant on several factors including the duration and magnitude of the imposed demand curtailment during each drought stage. In practice, the effectiveness of each stage due to factors including enforcement, public perception, demand hardening, ect., may reduce the magnitude of water saved as a result of implementing drought management measures.

Although, the additional supplies made available are not reliable, the volume of water saved can be significant. In Lake Livingston, over 150,000 afy was saved in the year 1956 alone. Although the water savings in this year is greater than the 2060 municipal conservation strategies recommended in the 2006 Region H Plan (101,200 afy), the volume is only available in roughly 2% of the years over the period of record. The conservation strategy however, reduces shortages in normal and dry hydrologic years. While DCP measures only produced additional annual supplies in 60% of the modeled years, the additional supplies could be used on an interruptible basis to provide freshwater inflows into Trinity Bay during drought conditions. Water savings in the San Jacinto and Brazos Basins were not as significant. 12,500 afy of additional supply would be available from Lake Conroe in approximately 5% of the years modeled. Modeling DCP effects on Lake Houston resulted in a maximum water savings of over 4,000 afy in 2% of the years modeled. Similarly, Allens Creek had a maximum water savings of over 5,000 afy available in approximately 4% of the years modeled. Table 21 shows the reliability of additional minimum (>0 afy) and maximum supplies made available by implementation of drought management measures.

Table 21. Reliability of Additional Supplies

Source	Source_ID	Reliability of Minimum Annual Supply		Reliability of Maximum Annual Supply	
		Volume	Reliability	Volume	Reliability
Lake Livingston	084H0	>0	60%	>150,000	2%
Lake Conroe	12900	>0	42%	>12,500	5%
Lake Houston	10030	>0	28%	>4,000	2%
Allens Creek	10060	>0	30%	>5,000	4%

As can be seen in Table 21, the additional supplies are not reliable enough to be allocated to municipal and industrial uses which generally require a high degree of water reliability. The supplies could however, be used to supplement existing water rights that are less than 100% reliable. The conjunctive use of an interruptible water right and water saved through implementation of DCP measures could be used to meet demands requiring "firm" supplies in lieu of more costly water management strategies. Identifying potential uses for a conjunctive use strategy depends on several factors including the proximity of demands and the timing of the interruptible supply shortage and the water made available through DCP measures. In the Trinity Basin, a surplus of water is available for consumptive use diminishing any incentive for developing a conjunctive use strategy. In the San Jacinto basin, significant municipal shortages (120,973 afy)[1] are projected in Harris County by 2020 and are projected to be met primarily by importing water from the Trinity Basin into Lake Houston via the Luce Bayou Project. The maximum annual supply that could be made available in Lake Houston and Lake Conroe through DCP measures (16,500 afy) would not be capable of meeting the 2020 projected municipal shortage in Harris County even with reduced demands during drought of record conditions. Additional supplies in Lake Livingston would not be accessible to areas in Harris County with projected shortages without the Luce Bayou Project to convey the water to Lake Houston. Additional supplies from Allens Creek could only be made available in approximately 30% of the years over the period of record and could only produce a maximum of 5,000 afy with an annual reliability of 4%. Additional supply from Allens Creek does not have a high reliability required to be allocated as part of a conjunctive use strategy to meet municipal demands.

Additional supplies could also be utilized through the effective implementation of drought management measures in cases where reservoir firm yield is below the permitted amount. Lake Livingston, Houston and the future Allens Creek reservoir are all projected to be firm through the planning period. Lake Conroe, however, is projected to have a firm yield of 74,300 afy in the year 2060, short of the permitted 100,000 afy. An additional 25,600 afy of supply from Lake Conroe could be utilized if a successful drought plan is implemented. Due to the length and severity of drought conditions on Lake Conroe, a successful plan would likely require the use of ground water as an alternative source of supply during low lake levels. This would allow a conjunctive use of an additional 25,600 afy of supply from Lake Conroe and groundwater to be used to meet municipal demands in Montgomery County. This would reduce the need for an inter basin transfer of supplies from the Trinity Basin to meet demands in the San Jacinto Basin. Currently, 50,000 acre-ft of TRA supply in Lake Livingston is projected to be contracted by SJRA and transferred to Lake Houston via Luce Bayou to meet demands in Montgomery County. Use of additional supplies from Lake Conroe would reduce the magnitude of the TRA – SJRA transfer from 59,000 afy to approximately 33,400 afy, although the magnitude of this alternative is not sufficient to offset the need for a project to provide water from the Trinity River Basin in Montgomery County. In addition, the use of groundwater

[1] 2006 Region H Water Plan Chapter 4, Table 4-1

during a drought of record to off-set surface water shortages is a concept that would require planning and approval by local regulatory agencies (i.e., Lone Star Groundwater Conservation District). The LSGCD is developing groundwater reduction rules for Montgomery County which will require the conversion from groundwater to an alternative (i.e., surface water) source of water over time. A strategy utilizing conjunctive use of groundwater during drought conditions would need to be approved by LSGCD as part of the overall conversion strategy for Montgomery County.

Due to the interruptible nature of water saved through drought management measures, the additional supplies can not be allocated to additional users as “firm” water. The additional supplies could however, be utilized conjunctively with another supply as part of a conjunctive use strategy affecting the timing and magnitude of water management strategies recommended in the 2006 Region H Water Plan. Table 22 lists the water management strategies recommended in the 2006 Region H water plan and identifies the possible impacts on the timing and magnitude of the selected strategies.

Table 22.Water Management Strategies Possibly Impacted by Drought Management

WMS	Yield(ac-ft/yr)	Starting Decade	Impact to Implementation
Municipal Conservation	101,200	2000	-
Irrigation Conservation	77,900	2010	1
Industrial Conservation	TBD	2000	-
Expanded Use of Groundwater	91,497	2010	-
Expand/Increase Current Contracts	68,300	2010	-
New Contracts from Existing Supply	215,400	2010	-
Luce Bayou IBT Conveyance	N/A	2020	-
BRA System Operations Permit	120,000	2010	-
Allens Creek Reservoir	99,700	2030	-
Little River Off-Channel Reservoir	32,100	2050	-
Non-Municipal Contractual Transfers	21,000	2010	-
Wastewater Reuse for Industry	67,200	2020	-
TRA to Houston Contract	150,000	2030	-
TRA to SJRA Contract	50,000	2030	2
Houston to GCWA Transfer	42,000	2010	-
Houston Indirect Wastewater Reuse	98,000	2050	-
NHCRWA Indirect Wastewater Reuse	31,400	2060	-
Lake Houston Additional Yield	13,500	2010	-
Freeport Seawater Desalination	33,600	2020	-
Brazos Saltwater Barrier	N/A	2030	-
Redesignation of Existing Water Rights	N/A	2010	-
New San Jacinto River Water Rights	0	2010	-
New Harris County Bayous Water Rights	0	2010	3

NOTES:
1. It is feasible that additional supplies made available during drought conditions could be allocated to irrigators on an interruptible basis; however this use is not recommended in lieu of implementing irrigation conservation.
2. Conjunctive use of Lake Conroe supplies and groundwater could provide an additional 25,600 acre-ft of reliable supply to Montgomery County delaying the starting decade from 2030 to 2060 and reducing the strategy volume.
3. Saving water during drought periods in addition to capturing interruptible water at Lake Houston will reduce operational costs associated with transferring supply from the Trinity Basin.

In general the use of water saved through the implementation of drought contingency measures is limited to an interruptible or conjunctive use supply source. The use of additional supplies made available in Lake Livingston prior to the construction of the Luce Bayou Project would be inaccessible to projected demands in the San Jacinto Basin; lacking the required conveyance infrastructure. As a result, water saved in Lake Livingston would be more beneficial to preserving lake levels and freshwater inflows into Trinity Bay. Similarly water saved in Lake Houston would not impact the size and timing of the recommended water management strategies, but would help reduce operational costs associated with transferring supply from Lake Livingston. Additional supplies in Allens Creek would be available only 30% of the years modeled. This would limit its use as an interruptible supply and would be more beneficial as extra storage in the event that drought conditions exceeded the drought of record. The most effective use of drought management to provide additional supply is found in Lake Conroe requiring the conjunctive use of surface water and ground water. Successful implementation of a conjunctive use strategy would be able to provide 25,600 afy of supply from Lake Conroe reducing the volume of water projected to be transferred from TRA to SJRA and delaying need for the transfer until 2060. The full utilization of existing supplies through a conjunctive use strategy would be recommended before inter-basin transfers.

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Section 8 – Summary and Closing Remarks

The components of drought contingency planning and the quantitative impacts that drought contingency measures potentially had on water supplies in Region H were investigated in this study. The study included a survey of the TCEQ drought impact plan. 133 public water suppliers were found to have been on the TCEQ drought impact list one or more times between 1996 and 2008. The majority of these systems are located in Harris County (24%) and Montgomery County (32%).

Most of the systems on the list were very small in size, it was found that 74% of them serve less than 1,000 connections. The Majority of systems (79%) rely on groundwater supplies. Based on TCEQ classifications, most utilities only required voluntary measures (35%) or mild "rationing" (47%); some (16%) were classified as having implemented severe 'rationing"

Analyzing the drought impact list yielded that there is no indication that any Region H public water systems have experienced an "actual" water shortage situation in recent history. Available information indicates that the reason those systems were on the TCEQ list was because of water production and/or distribution infrastructure limitations relative to high seasonal peak water demands.

The effectiveness of drought response measures was also investigated as part of this study; the study found that there is very little "good" empirical research to quantity the effectiveness of drought response measures. Most water suppliers that have implemented DCPs have not thoroughly evaluated the effects. "Post-event" analyses was found to typically only report "gross" changes in water demand, most commonly expressed as a percentage reduction. Most DCPs whether within Region H or nationwide specify multiple measures for each stage (e.g., restrictions, education, pricing). Those measures are always synergistic rather than additive effects and are difficult to isolate the discreet effects of specific measures.

It was also found that most DCPs in Texas are focused on seasonal peaking problems rather than actual water shortage and are always addressed at peak shaving.

Impact of drought contingency plans on Region H reservoirs was investigated in this study. It was found that DCPs have little near-term efficacy as current water demands are low relative to available supply. Efficacy of drought contingency planning will increase as demands on each source approach full permitted authorizations and/or the firm yield of the source. In general, implementation of DCPs could minimize the drawdown of Region H reservoirs and shorten the duration of impacts on lake levels during a repeat of drought-of-record conditions. However, the analysis indicated that this "stretching" of water supplies due to drought contingency measures are relatively insignificant in terms of an annual increased supply. While implementation of drought contingency measures can save substantial volumes of water during drought of record conditions, little to no water is made available during normal hydrologic conditions. As a result, the water saved is only available on an interruptible basis and does not represent an increase in annual supply. The allocation of an interruptible supply as an annual supply to meet demands that are present in both normal hydrologic and drought conditions would be inconsistent with the purpose of long-term water planning. Water saved through implementation of drought contingency measures may be used on an interruptible basis as part of a conjunctive use strategy. Further more, the 150,000 acre-ft that is made available in Lake Livingston is not available in every year during the drought of record, much less every month. The DCP for Lake Conroe, for example, may warrant modification in the future to allow utilization of the full authorized diversion of 100,000 afy, which exceeds the estimated firm yield of 74,300 afy based on the projected 2060 area-capacity curve of reservoir.

Finally, impact of drought contingency plans on existing water management strategies in Region H was analyzed; it is necessary to mention that implementation of drought management plans will have effects on annual water demands when implemented during drought conditions. Reduced demands during drought conditions however, does not allow water supplies to be reallocated to meet demands elsewhere. Unlike conservation strategies, water savings from drought management are only available during drought conditions. As a result, supplies offset by the projected water savings cannot be reallocated to meet other demands.

So to go back to the key question of this study *"Can a strategy of implementing drought response measures (e.g., staged curtailment of water demands) within Region H during critical drought periods be used in lieu of recommended water management strategies to meet projected needs?"*

The results of this study indicate that, while drought contingency planning is a critical component of water supply management and may provide short-term benefits during severe drought conditions; drought management alone will not replace any recommended long-term water management strategies. This conclusion is based on the following:

1. According to the current Region H Plan, there are no unmet water supply needs associated with existing reservoirs.
2. The current Region H Plan, therefore, does not include water management strategies that could be replaced by demand curtailment during drought. However the magnitude and timing of the TRA to SJRA inter-basin transfer strategy would be affected by the conjunctive use of existing supplies in Montgomery County. Conjunctive use of existing supplies would be recommended prior to inter-basin transfers.
3. Implementation of DCPs would not "free up" water supply for use by others because the demand reduction would only occur during critical drought – demand curtailment is not the same as water conservation.
4. During "normal" conditions, water supply would be needed to meet full unconstrained demand.
5. Current TWDB policy for regional water supply planning requires that all identified water supply needs, based on drought-of-record conditions, be satisfied except in cases where there are no feasible strategies.
6. Drought contingency measures were shown to be effective in "stretching" water supplies during drought conditions. However, this "stretching" of supplies during drought were measured in terms of months and therefore, while this may be critical for an individual supply in crisis, is insignificant in the context of long-term water planning. Long term water planning assumes that only the firm yield from reservoirs is available for allocation. Water saved by implementing drought contingency measures would only be available on an interruptible basis during drought conditions. As a result, the saved water could only be allocated to meet demands that are present on an interruptible basis; that is, the increase in demands above normal hydrologic conditions in response to drought conditions. Under this scenario, implementation of drought contingency measures could be used to reduce dry year demands down to average year demand levels. Traditional supply sources and long-term water management strategies would still be required to supply average year demands.
7. Drought contingency planning and the various measures implemented to curtail demand during severe drought conditions are very critical components of any water supply management plan. These plans should be evaluated often and the actions enforced when needed to curtail demand and potentially extend water supplies during drought conditions. However, these measures alone will not replace the need to implement recommended long-term water management strategies.

APPENDIX A

Lake Livingston

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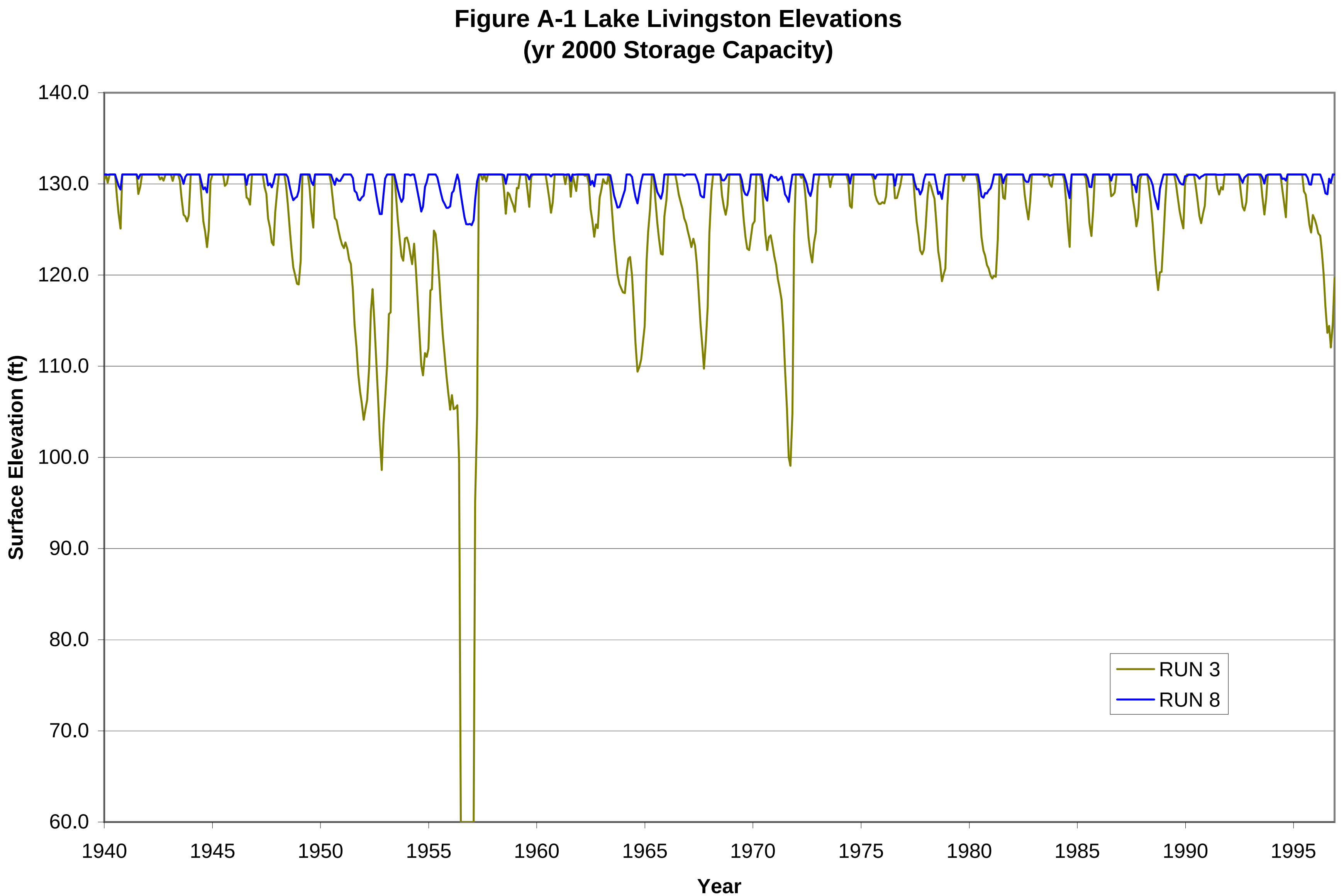


Figure A-1 Lake Livingston Elevations
(yr 2000 Storage Capacity)
Surface Elevation (ft)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8

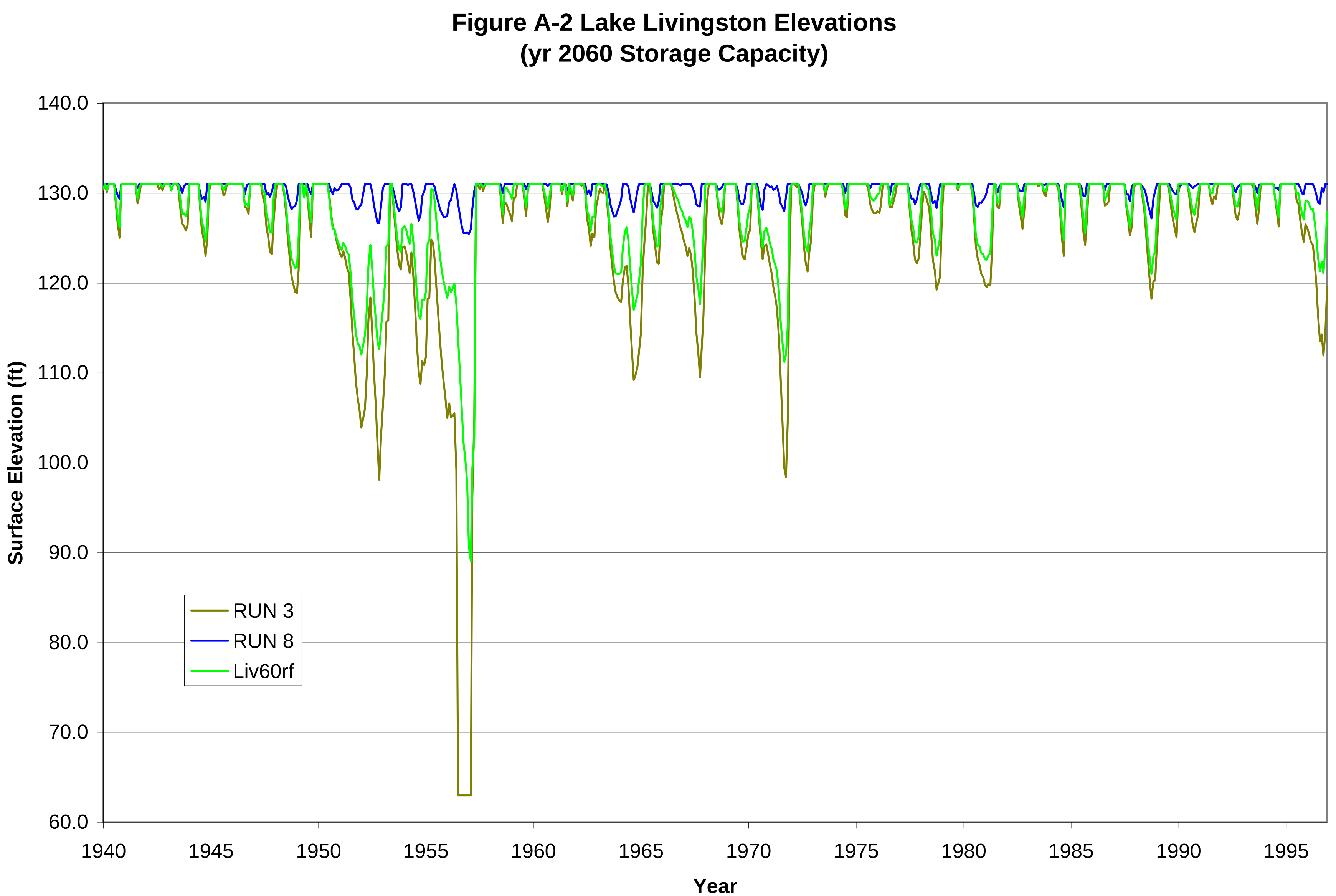


Figure A-2 Lake Livingston Elevations
(yr 2060 Storage Capacity)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
Surface Elevation (ft)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8
Liv60rf

10/28/2008

**Figure A-3 Lake Livingston Elevation Percentiles
(yr 2000 Storage Capacity)**

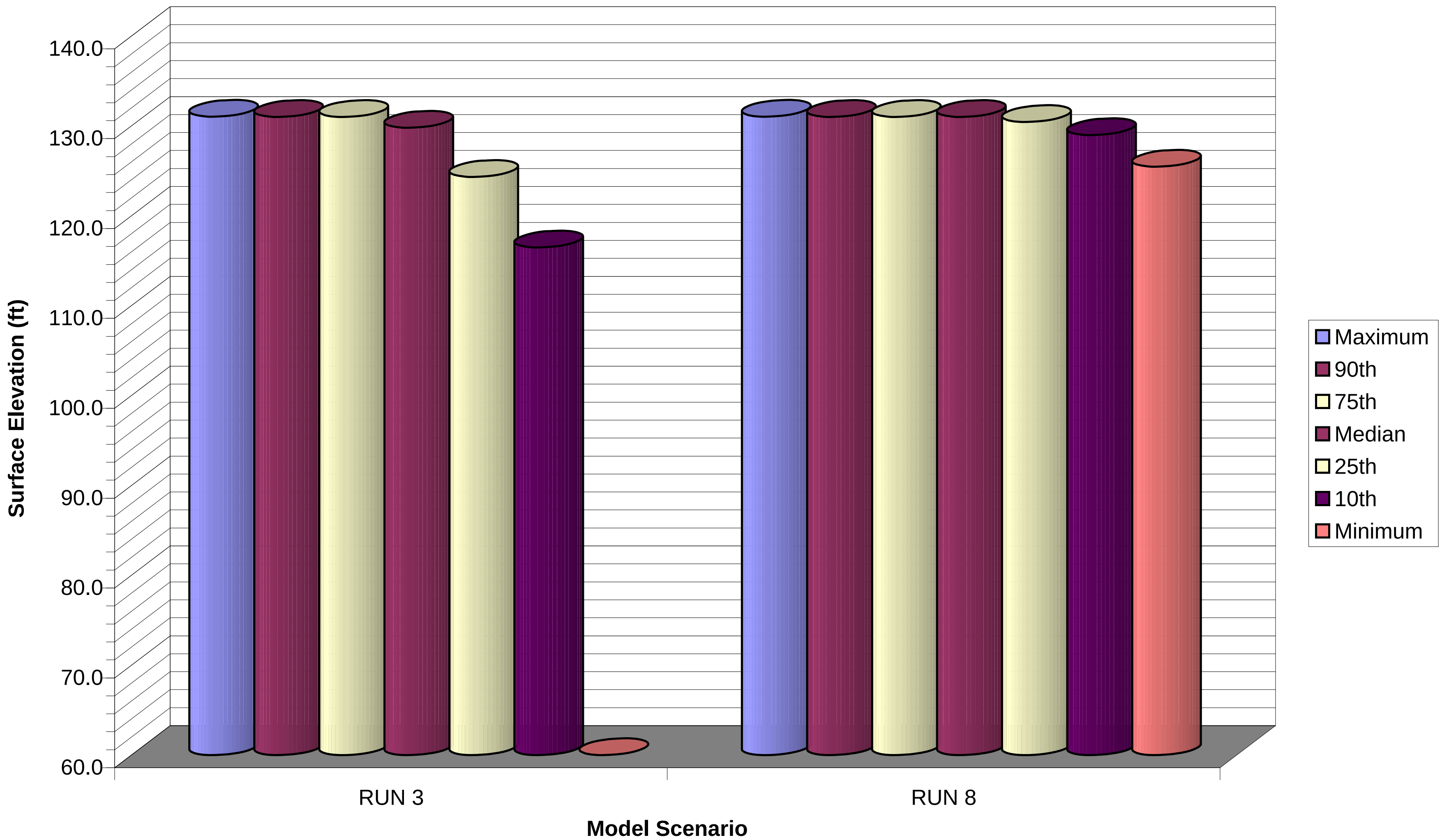
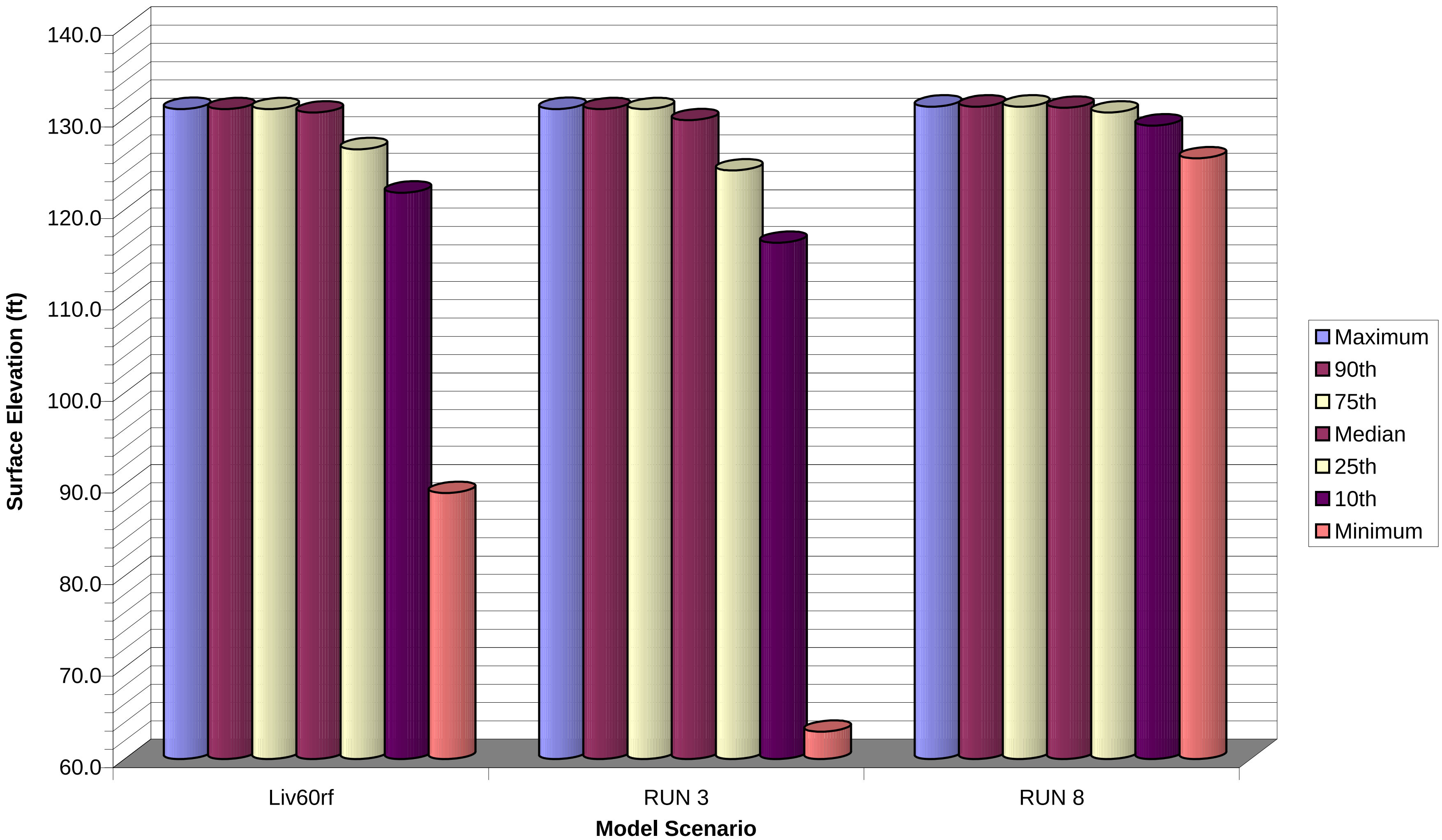


**Figure A-4 Lake Livingston Elevation Percentiles
(yr 2060 Storage Capacity)**



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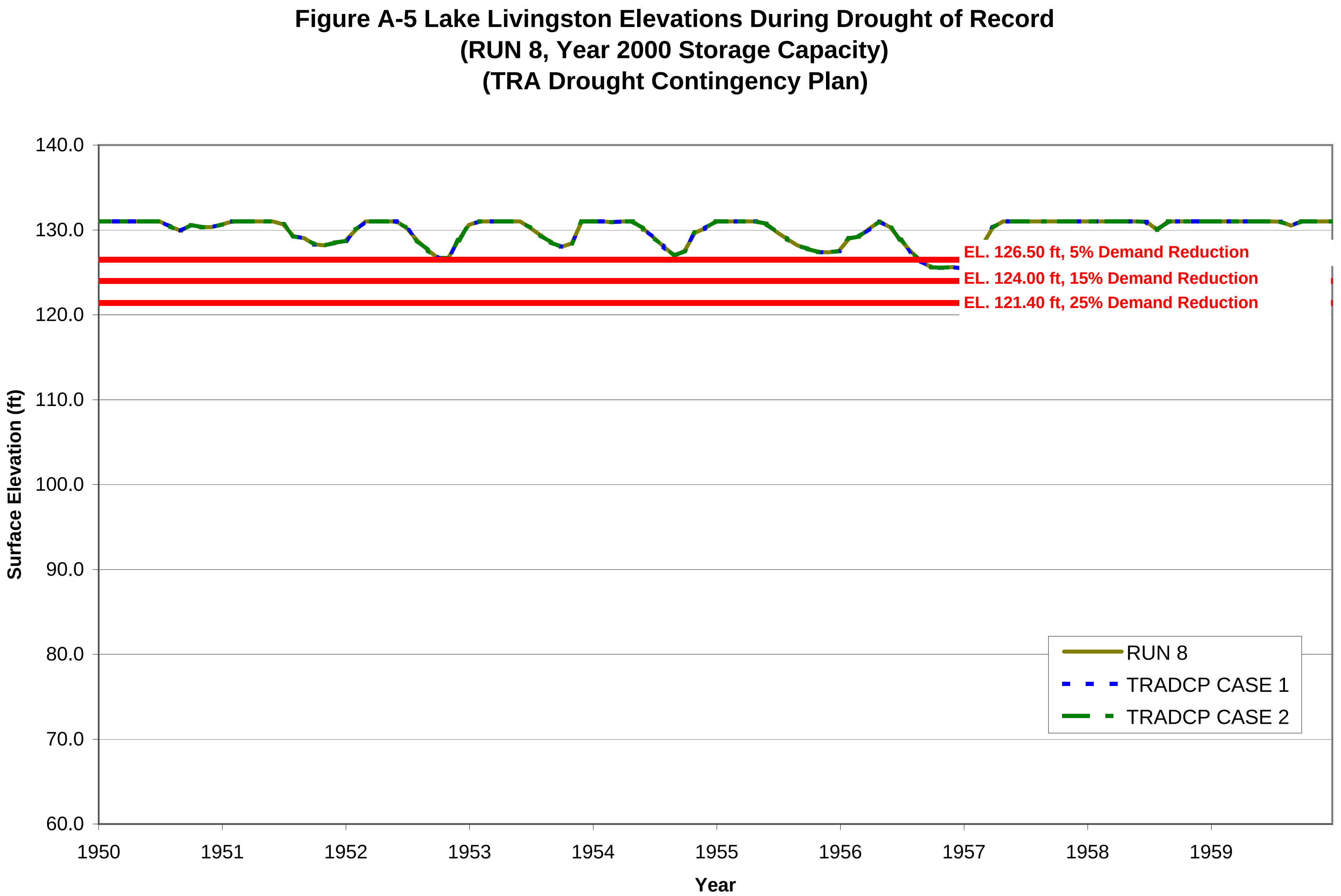
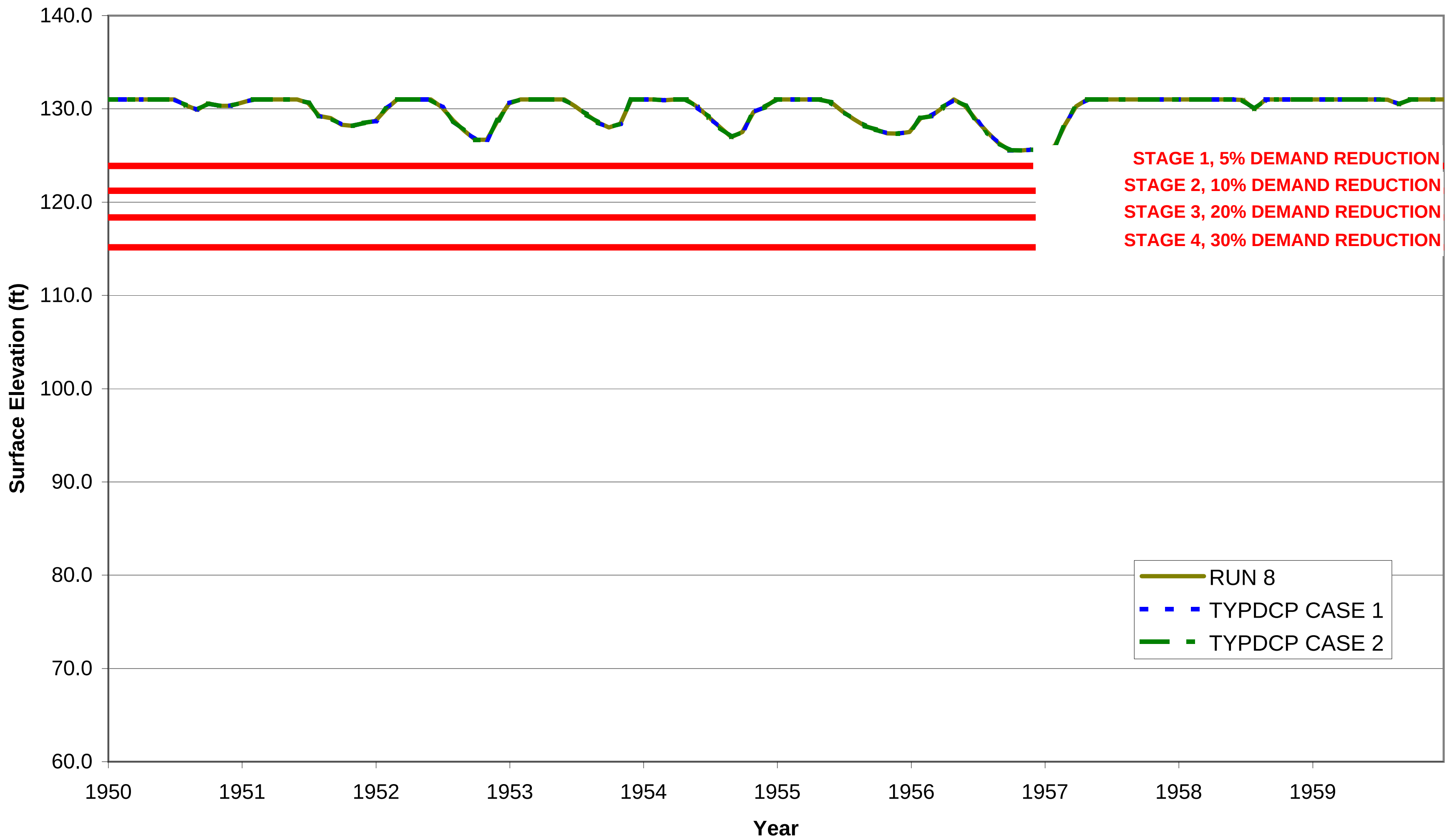


Figure A-5 Lake Livingston Elevations During Drought of Record
(RUN 8, Year 2000 Storage Capacity)
(TRA Drought Contingency Plan)
Surface Elevation (ft)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
EL. 126.50 ft, 5% Demand Reduction
EL. 124.00 ft, 15% Demand Reduction
EL. 121.40 ft, 25% Demand Reduction
RUN 8
TRADCP CASE 1
TRADCP CASE 2

Figure A-6 Lake Livingston Elevations During Drought of Record (RUN 8, Year 2000 Storage Capacity) (Typical Drought Contingency Plan)



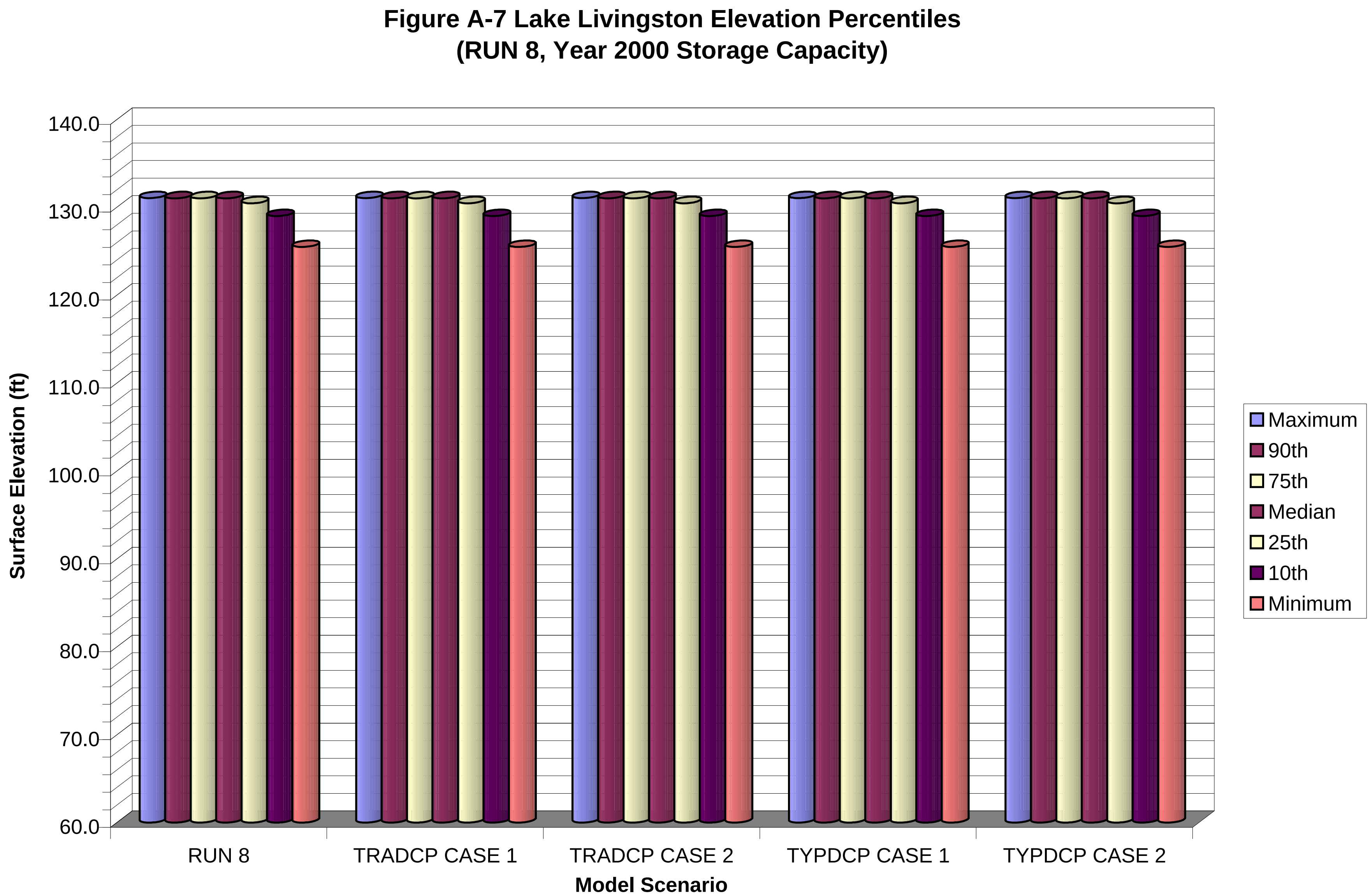
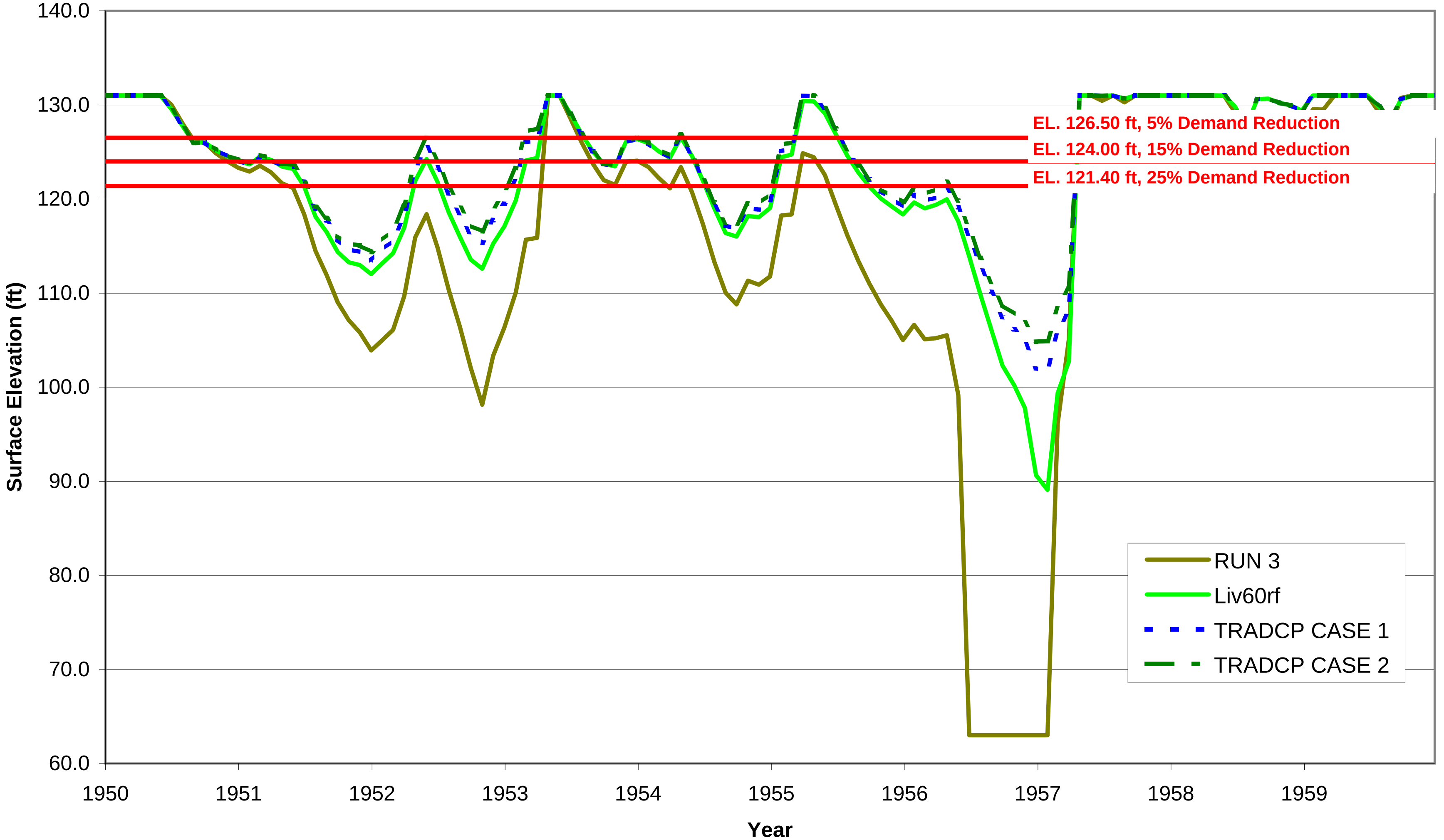


Figure A-7 Lake Livingston Elevation Percentiles
(RUN 8, Year 2000 Storage Capacity)
Surface Elevation (ft)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
RUN 8
TRADCP CASE 1
TRADCP CASE 2
TYPDCP CASE 1
TYPDCP CASE 2
Model Scenario
Maximum
90th
75th
Median
25th
10th
Minimum

Figure A-8 Lake Livingston Elevations During Drought of Record (yr 2060 Storage Capacity) (TRA Drought Contingeny Plan)



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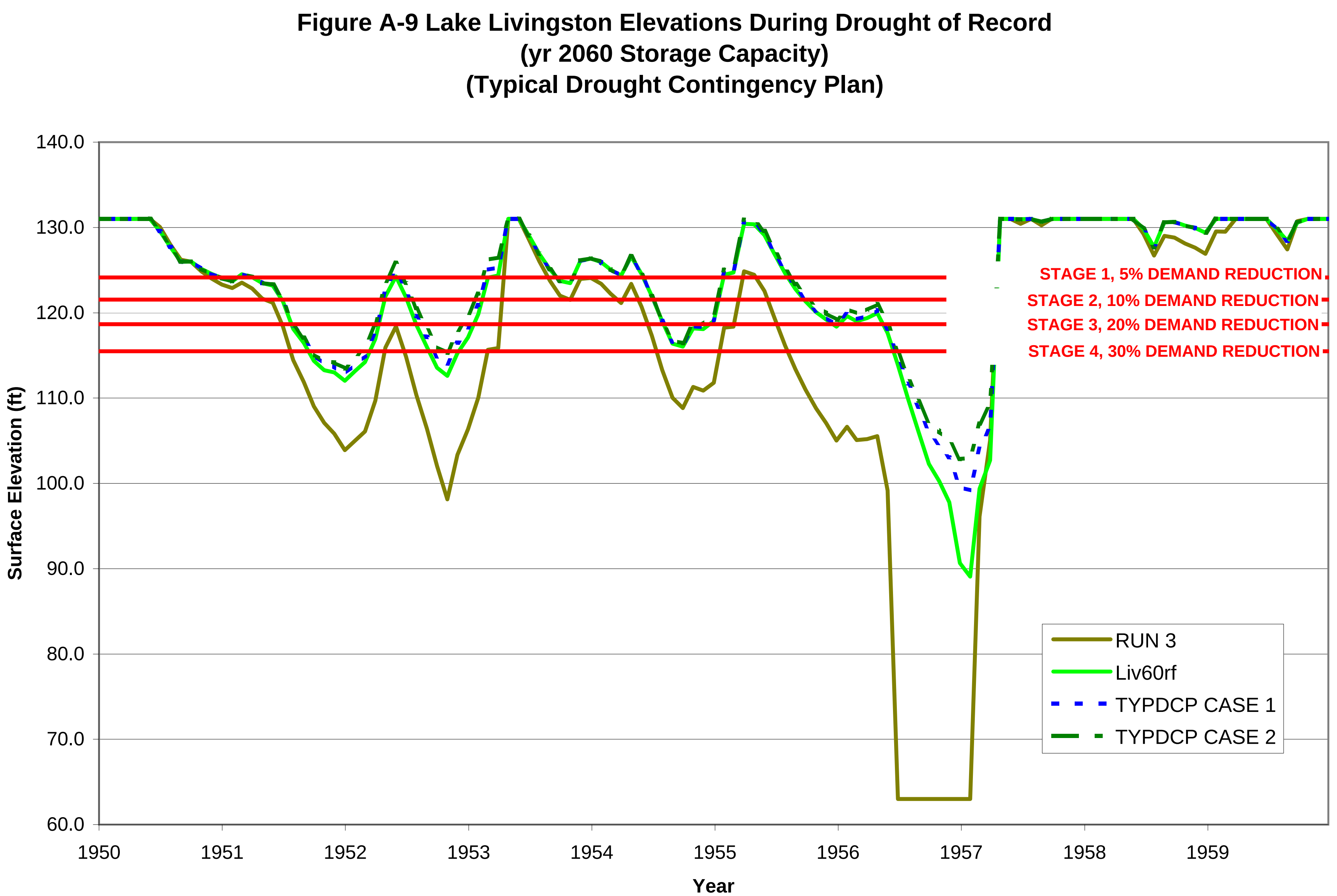


Figure A-9 Lake Livingston Elevations During Drought of Record
(yr 2060 Storage Capacity)
(Typical Drought Contingency Plan)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
Surface Elevation (ft)
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
RUN 3
Liv60rf
TYPDCP CASE 1
TYPDCP CASE 2

**Figure A-10 Lake Livingston Elevation Percentiles
Liv60rf, Year 2060 Storage Capacity**

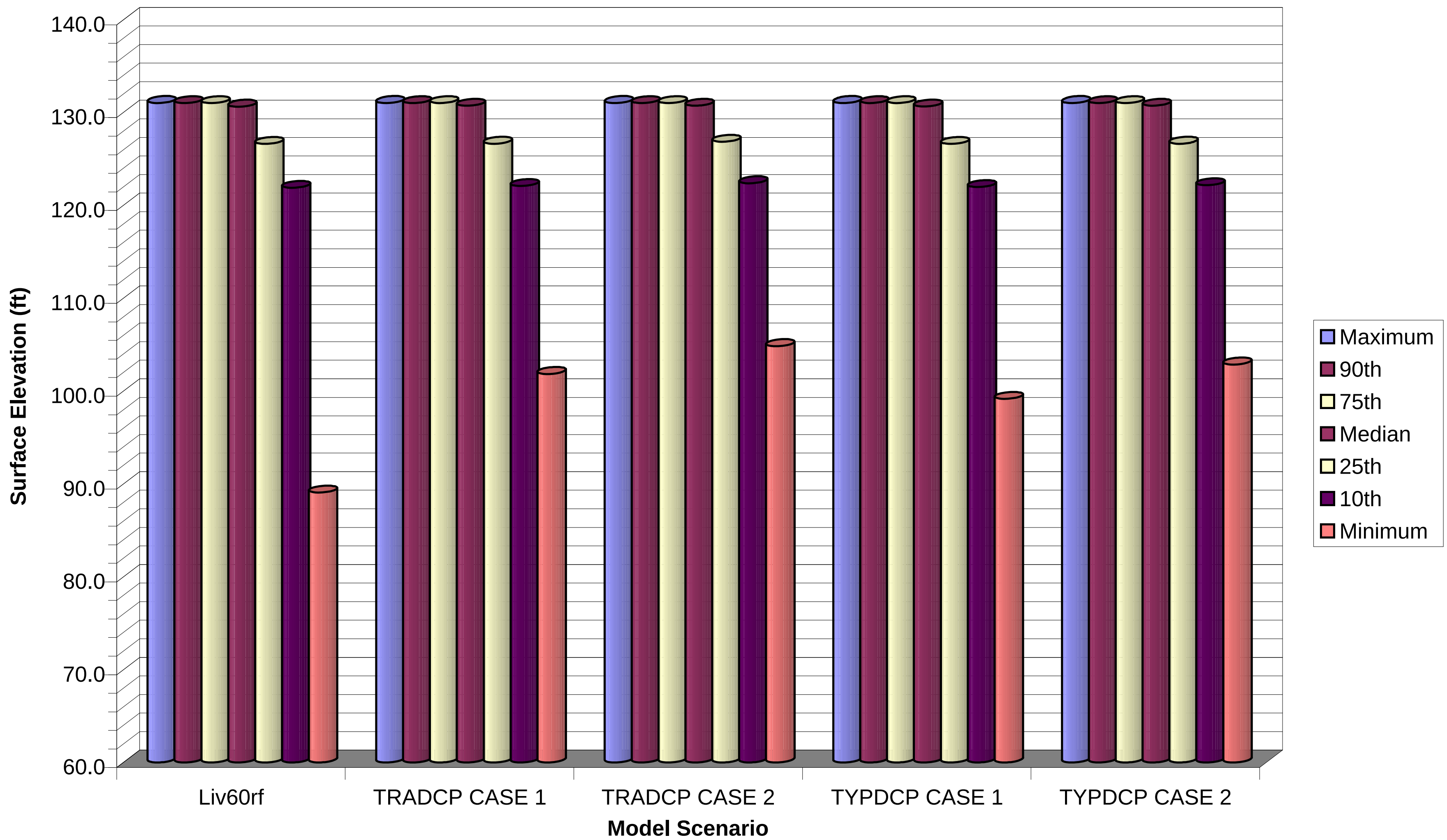
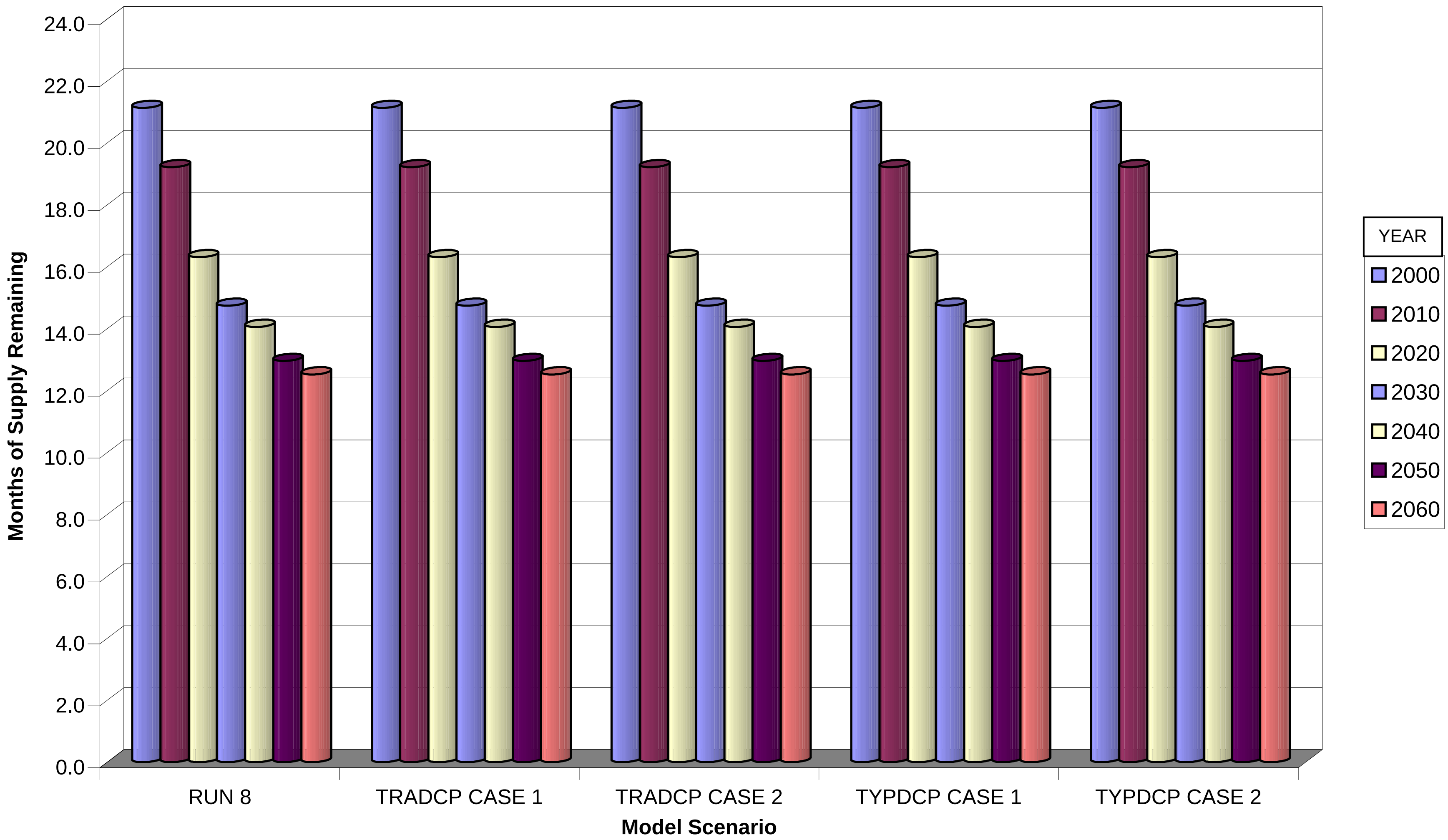


Figure A-11 Lake Livingston
Remaining Supply during Drought of Record
(RUN 8, Year 2000 Storage Capacity)



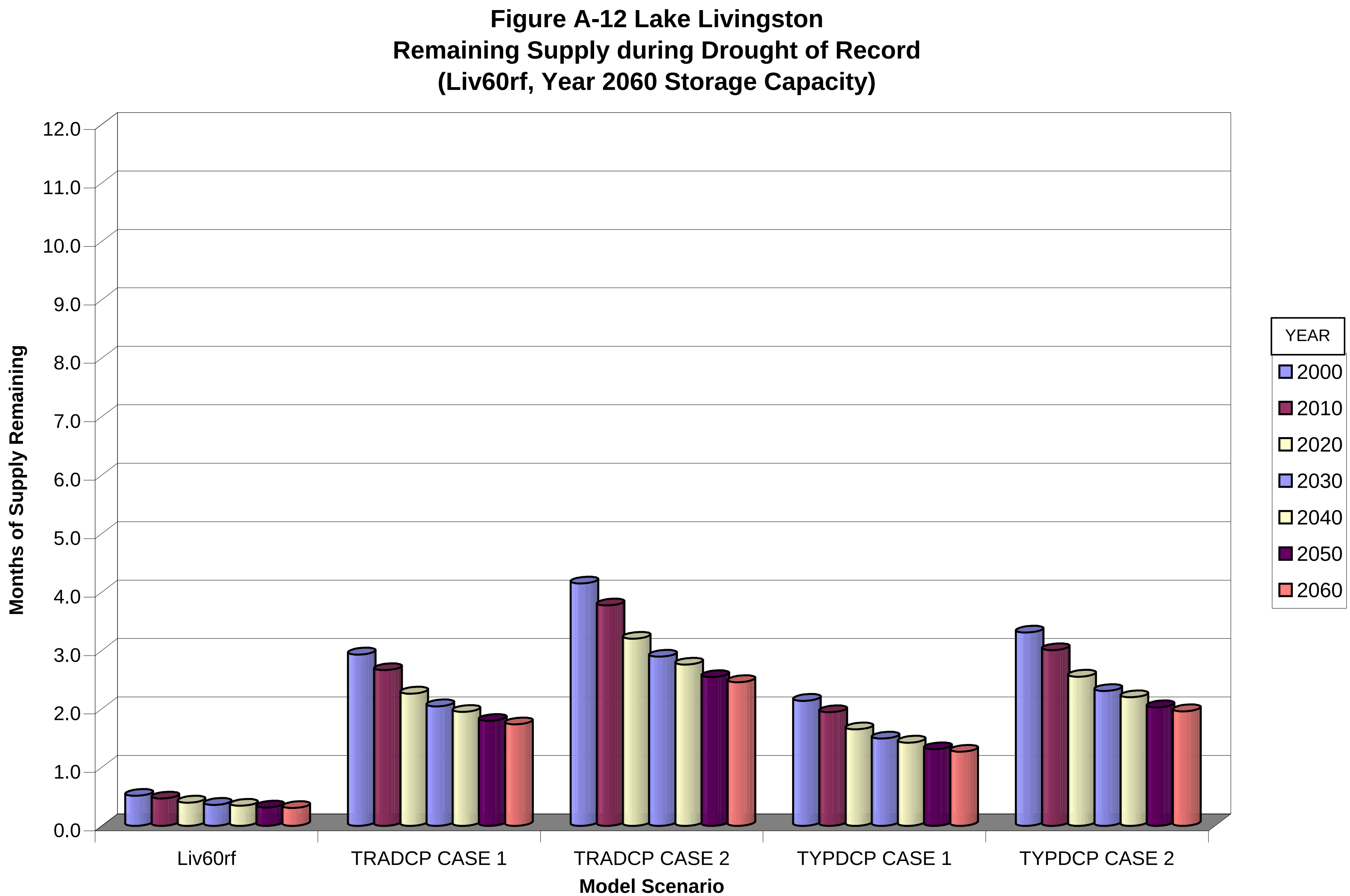


Figure A-12 Lake Livingston
Remaining Supply during Drought of Record
(Liv60rf, Year 2060 Storage Capacity)
Months of Supply Remaining
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Liv60rf
TRADCP CASE 1
TRADCP CASE 2
TYPDCP CASE 1
TYPDCP CASE 2
Model Scenario
YEAR
2000
2010
2020
2030
2040
2050
2060

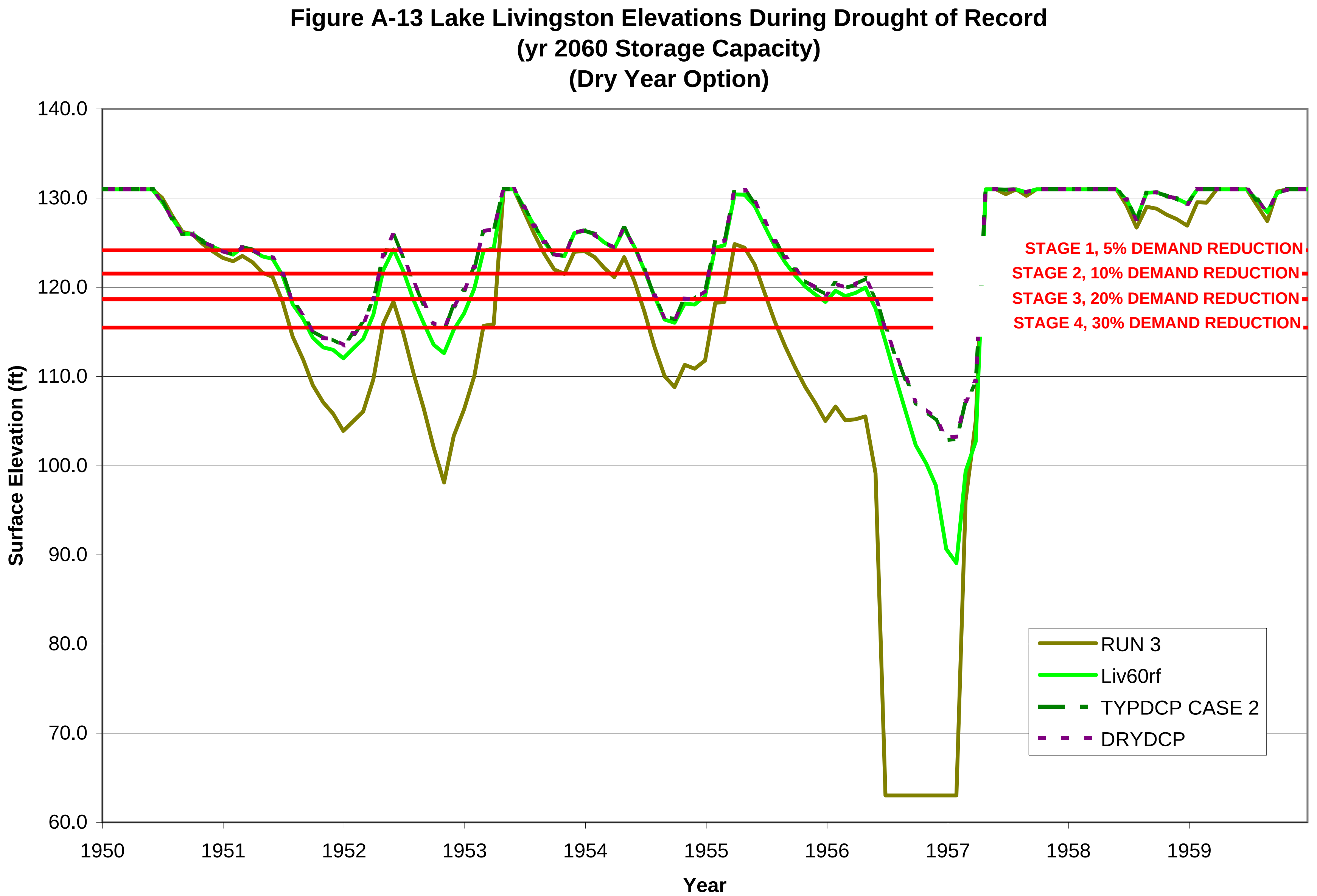


Figure A-13 Lake Livingston Elevations During Drought of Record
(yr 2060 Storage Capacity)
(Dry Year Option)
Surface Elevation (ft)
140.0
130.0
120.0
110.0
100.0
90.0
80.0
70.0
60.0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
RUN 3
Liv60rf
TYPDCP CASE 2
DRYDCP

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APPENDIX B

Lake Conroe

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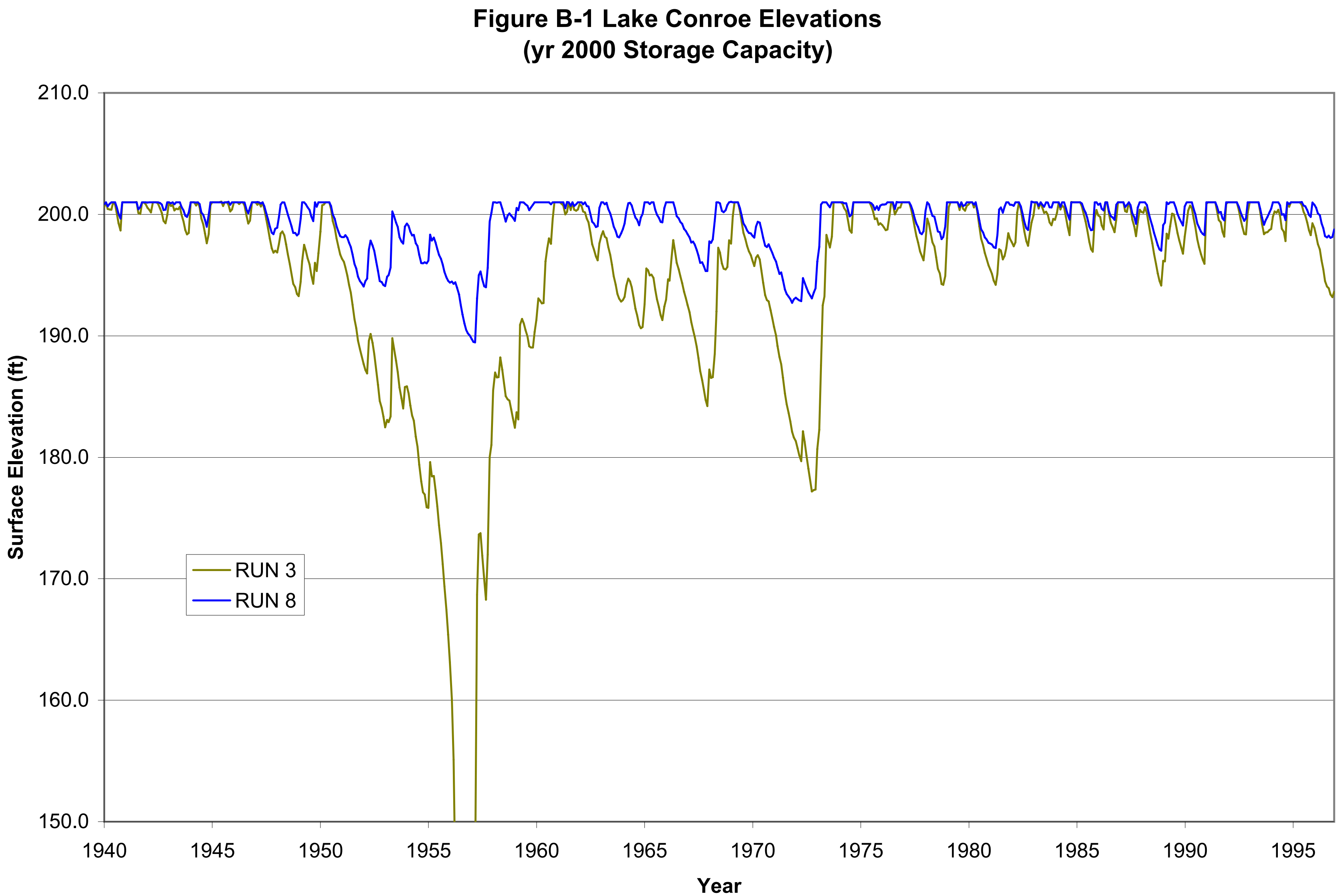
Figure B-1 Lake Conroe Elevations
(yr 2000 Storage Capacity)
210.0
200.0
190.0
180.0
170.0
160.0
150.0
Surface Elevation (ft)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8

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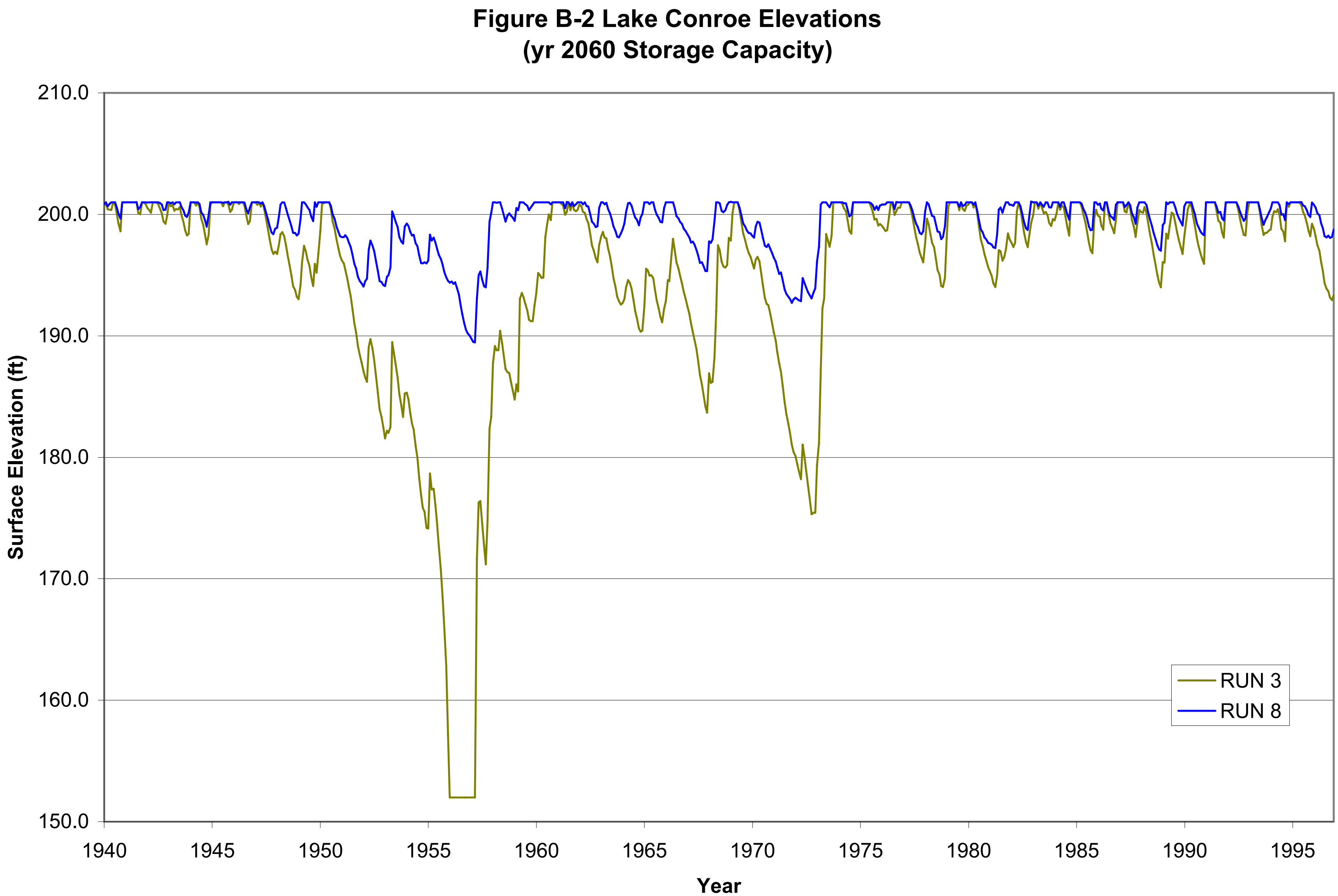
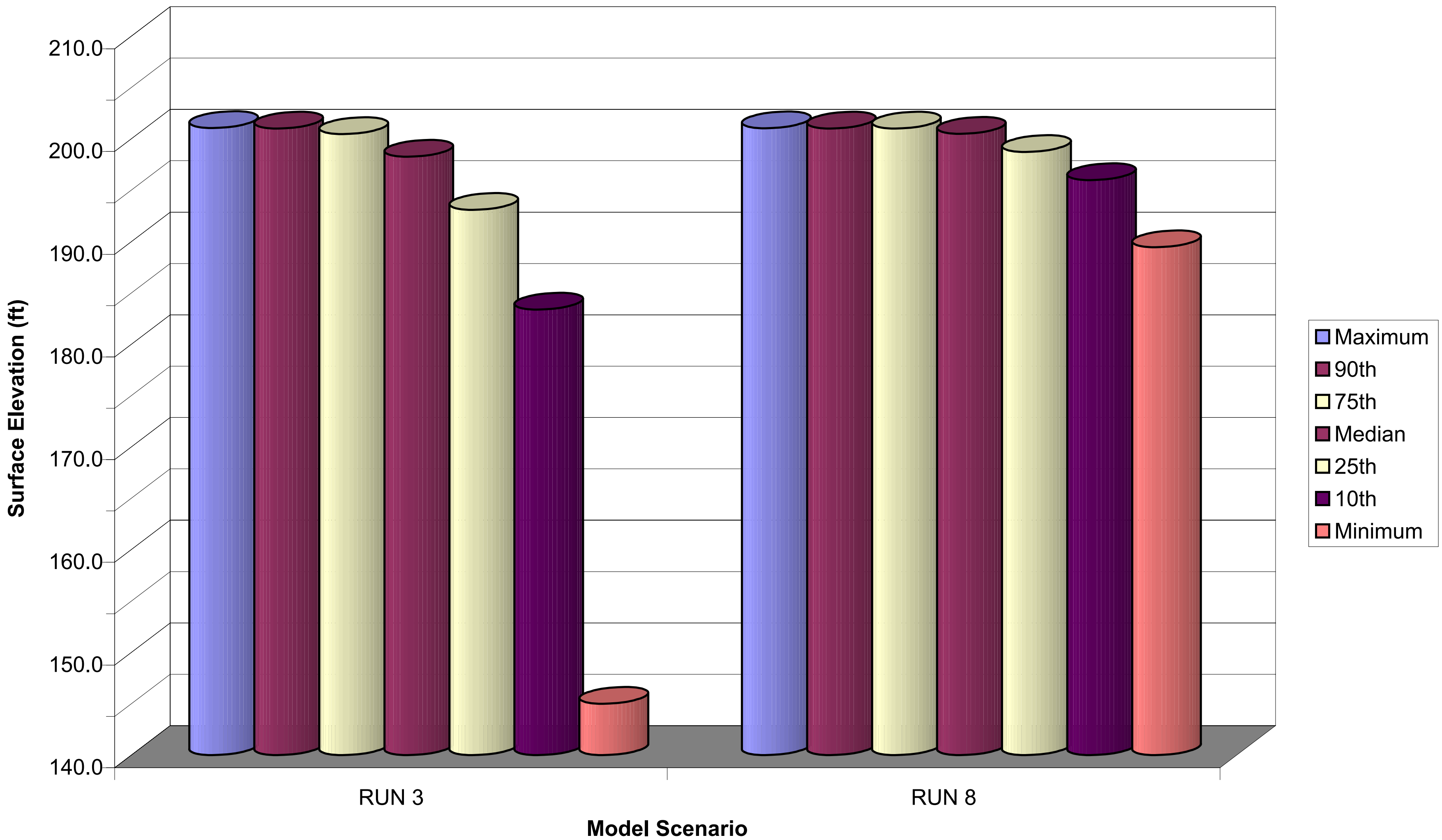


Figure B-2 Lake Conroe Elevations
(yr 2060 Storage Capacity)
Surface Elevation (ft)
210.0
200.0
190.0
180.0
170.0
160.0
150.0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8

Figure B-3 Lake Conroe Elevation Percentiles (yr 2000 Storage Capacity)



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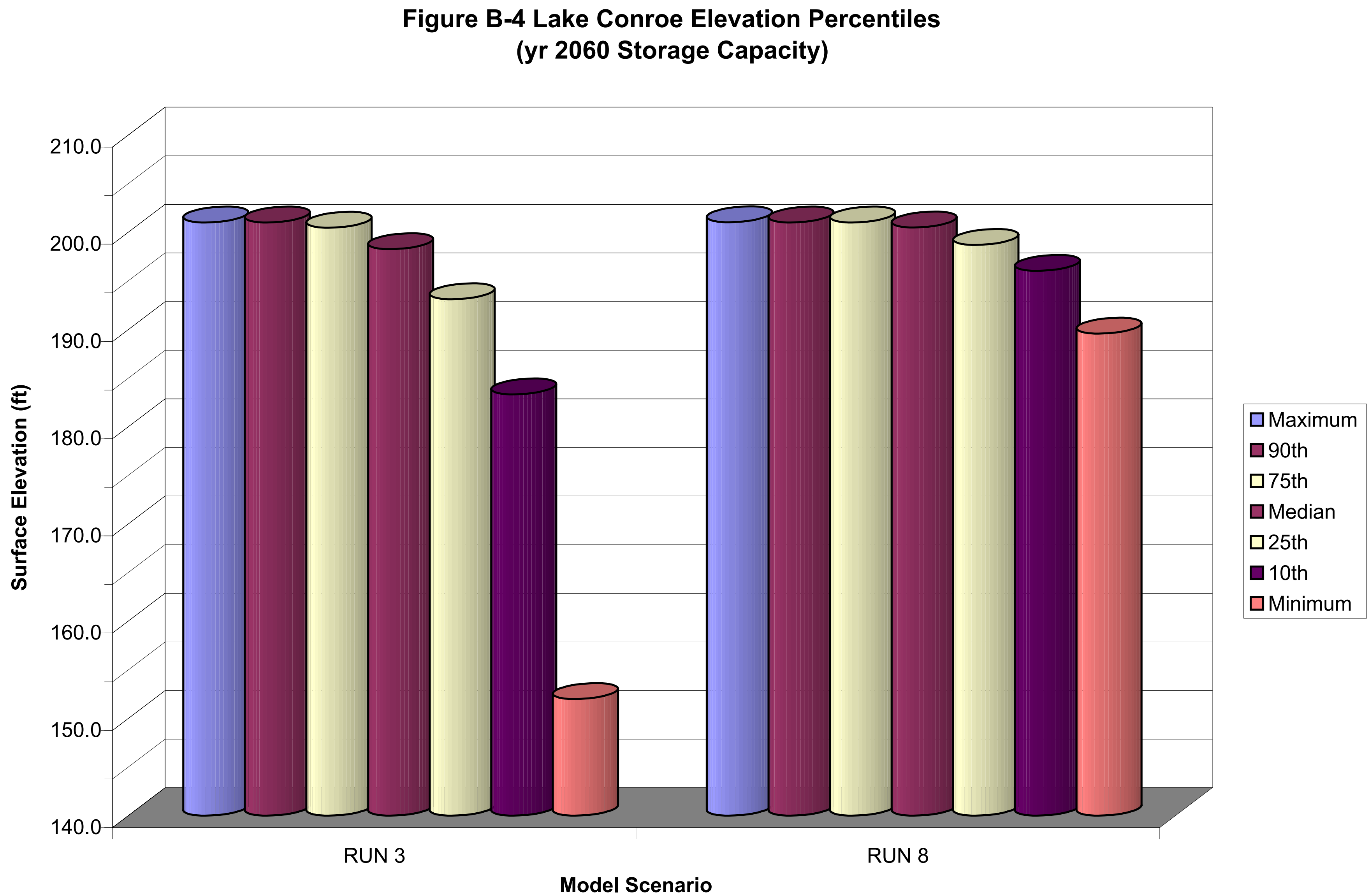
Figure B-4 Lake Conroe Elevation Percentiles
(yr 2060 Storage Capacity)
210.0
200.0
190.0
180.0
170.0
160.0
150.0
140.0
Surface Elevation (ft)
RUN 3
RUN 8
Model Scenario
Maximum
90th
75th
Median
25th
10th
Minimum

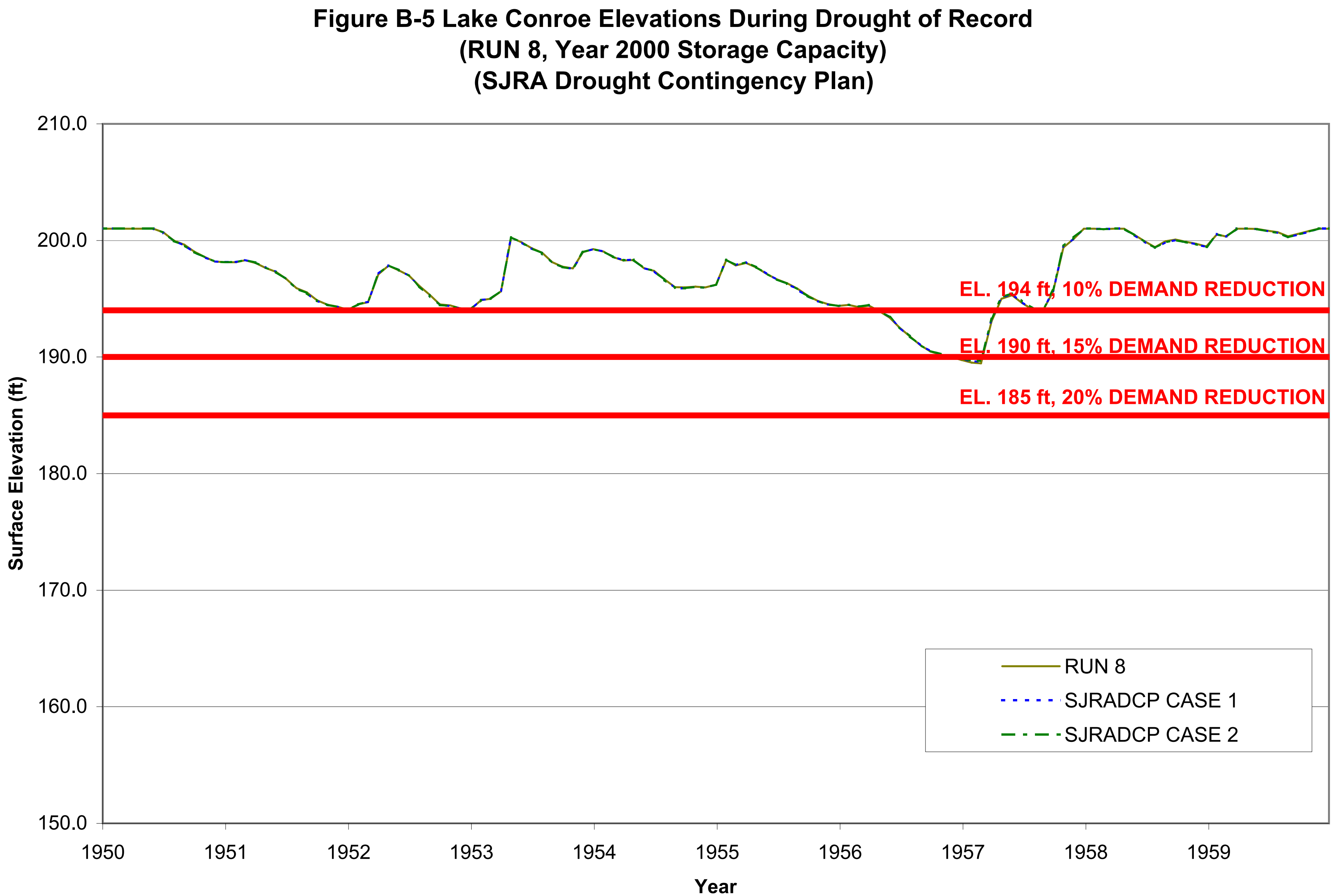
Figure B-5 Lake Conroe Elevations During Drought of Record
(RUN 8, Year 2000 Storage Capacity)
(SJRA Drought Contingency Plan)
Surface Elevation (ft)
210.0
200.0
190.0
180.0
170.0
160.0
150.0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
EL. 194 ft, 10% DEMAND REDUCTION
EL. 190 ft, 15% DEMAND REDUCTION
EL. 185 ft, 20% DEMAND REDUCTION
RUN 8
SJRADCP CASE 1
SJRADCP CASE 2

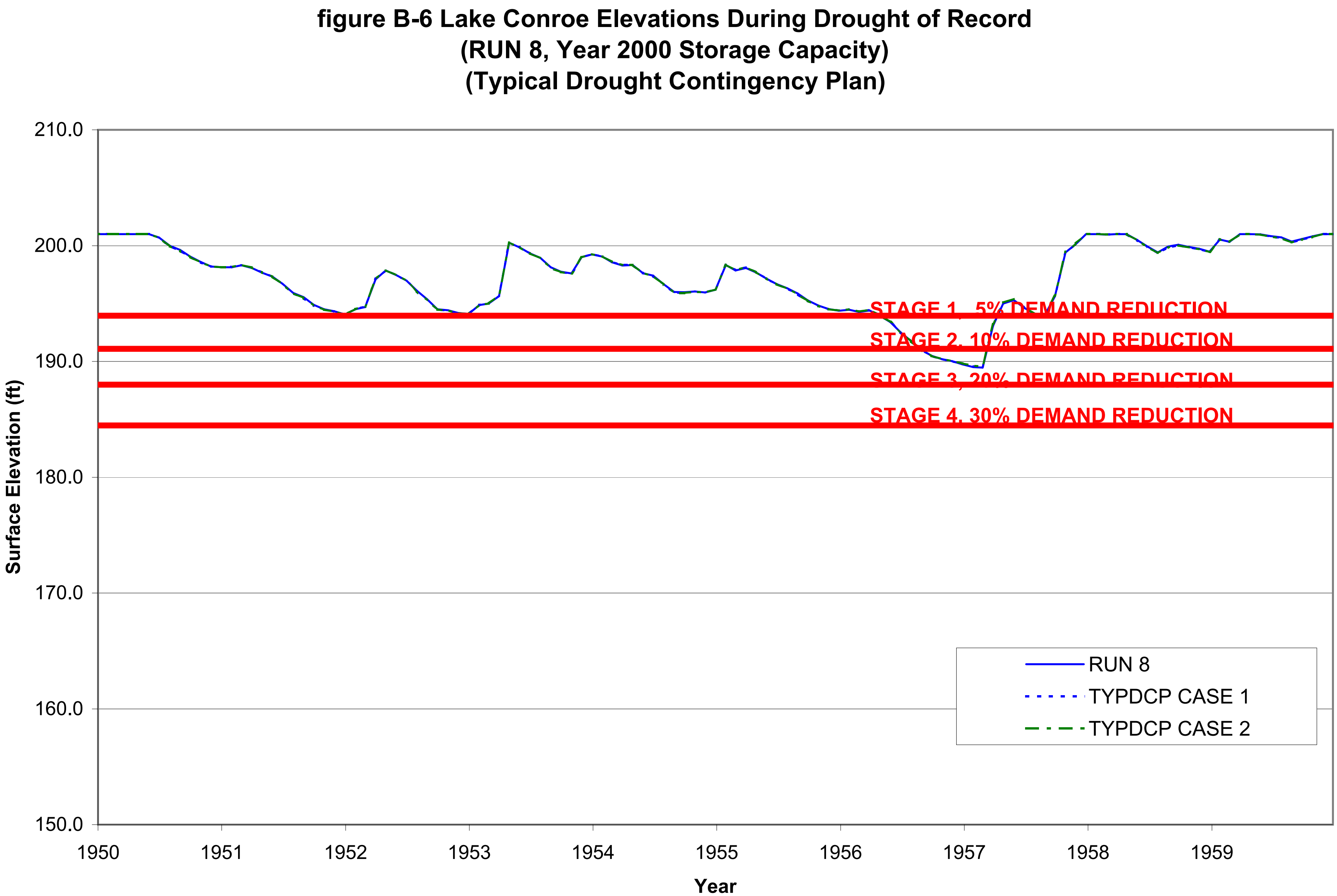
figure B-6 Lake Conroe Elevations During Drought of Record
(RUN 8, Year 2000 Storage Capacity)
(Typical Drought Contingency Plan)
Surface Elevation (ft)
210.0
200.0
190.0
180.0
170.0
160.0
150.0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
RUN 8
TYPDCP CASE 1
TYPDCP CASE 2

Figure B-7 Lake Conroe Elevation Percentiles (RUN 8, Year 2000 Storage Capacity)

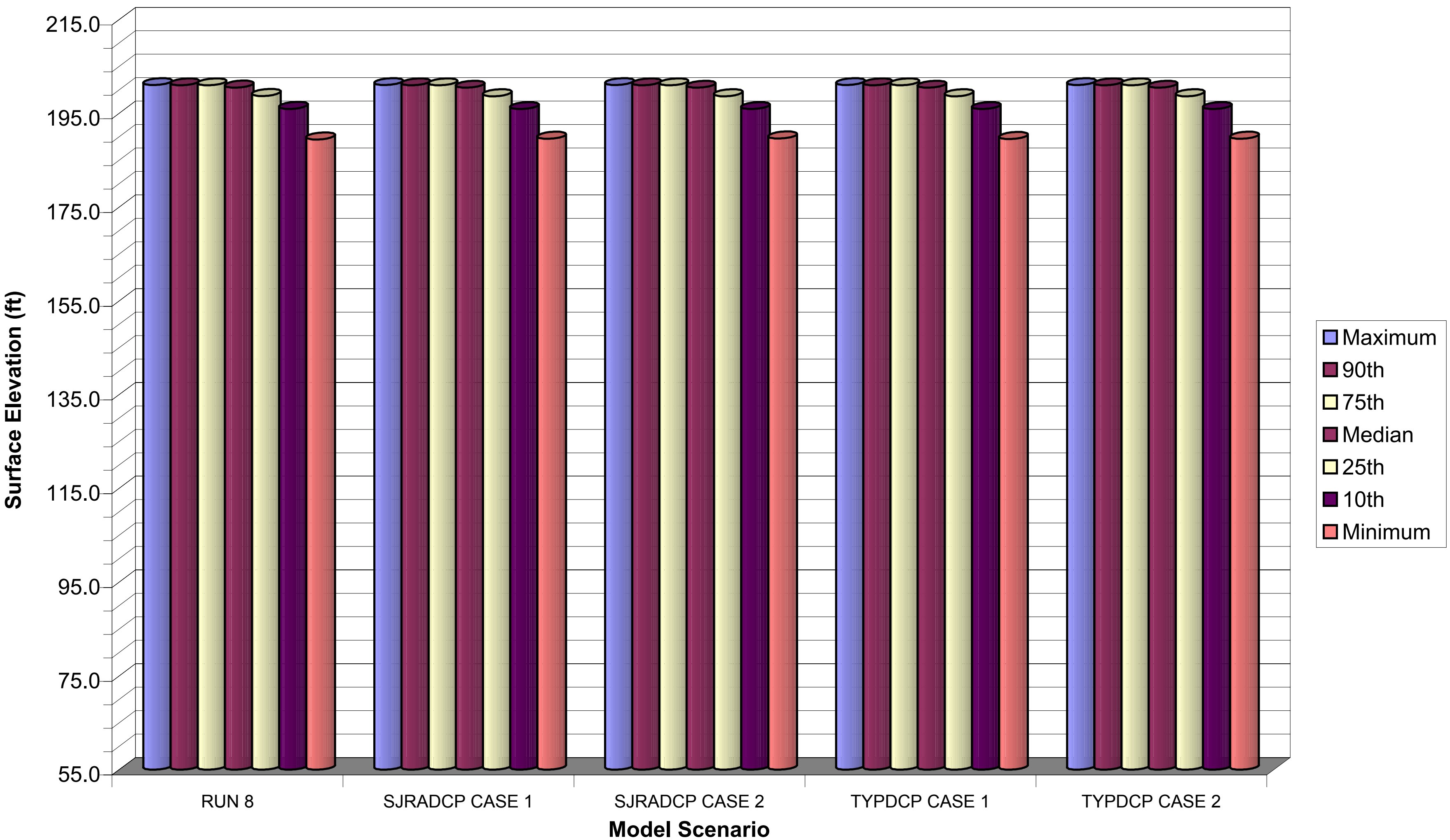

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Figure B-8 Lake Conroe Elevations During Drought of Record (yr 2060 Storage Capacity) (SJRA Drought Contingerncy Plan)

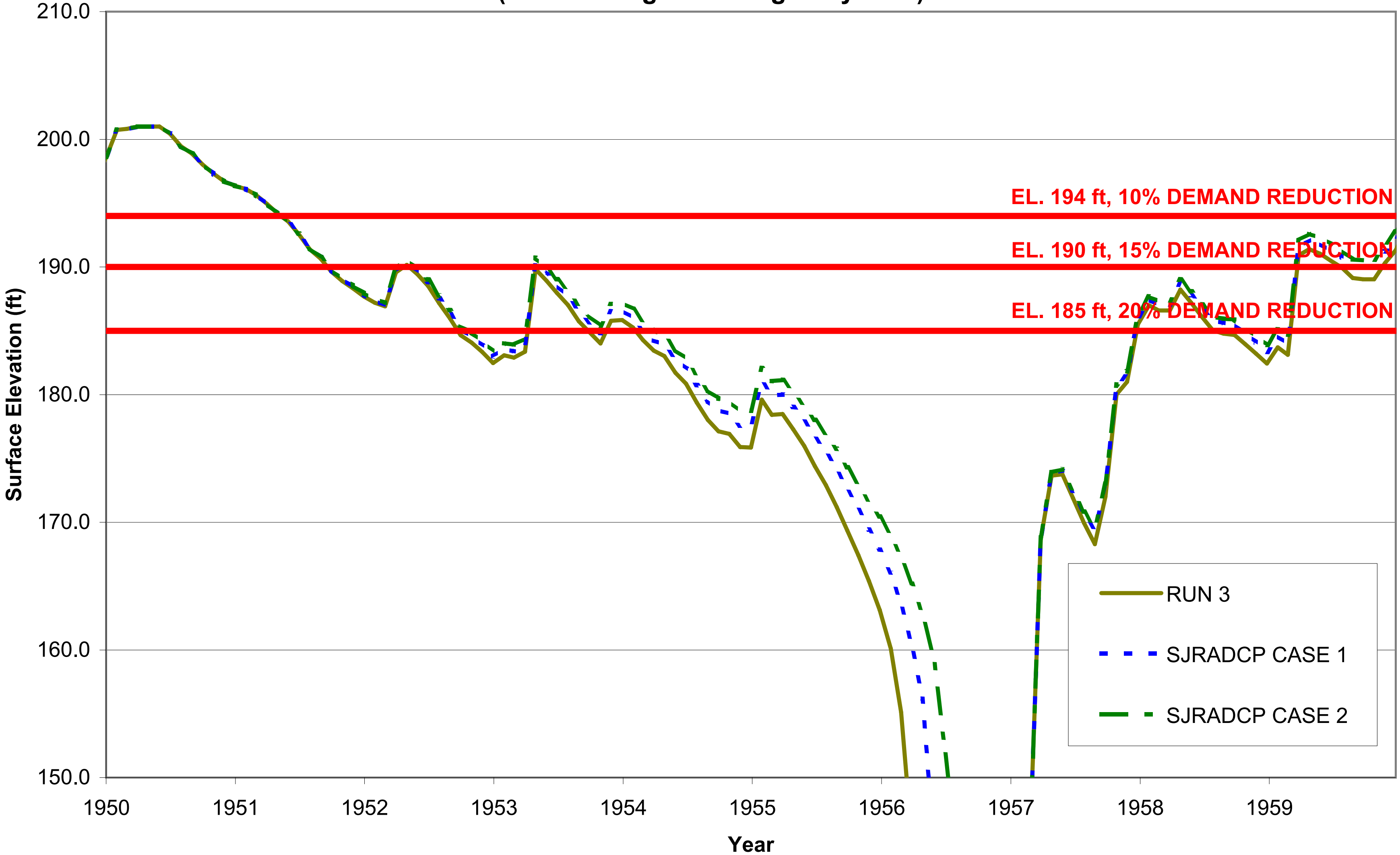

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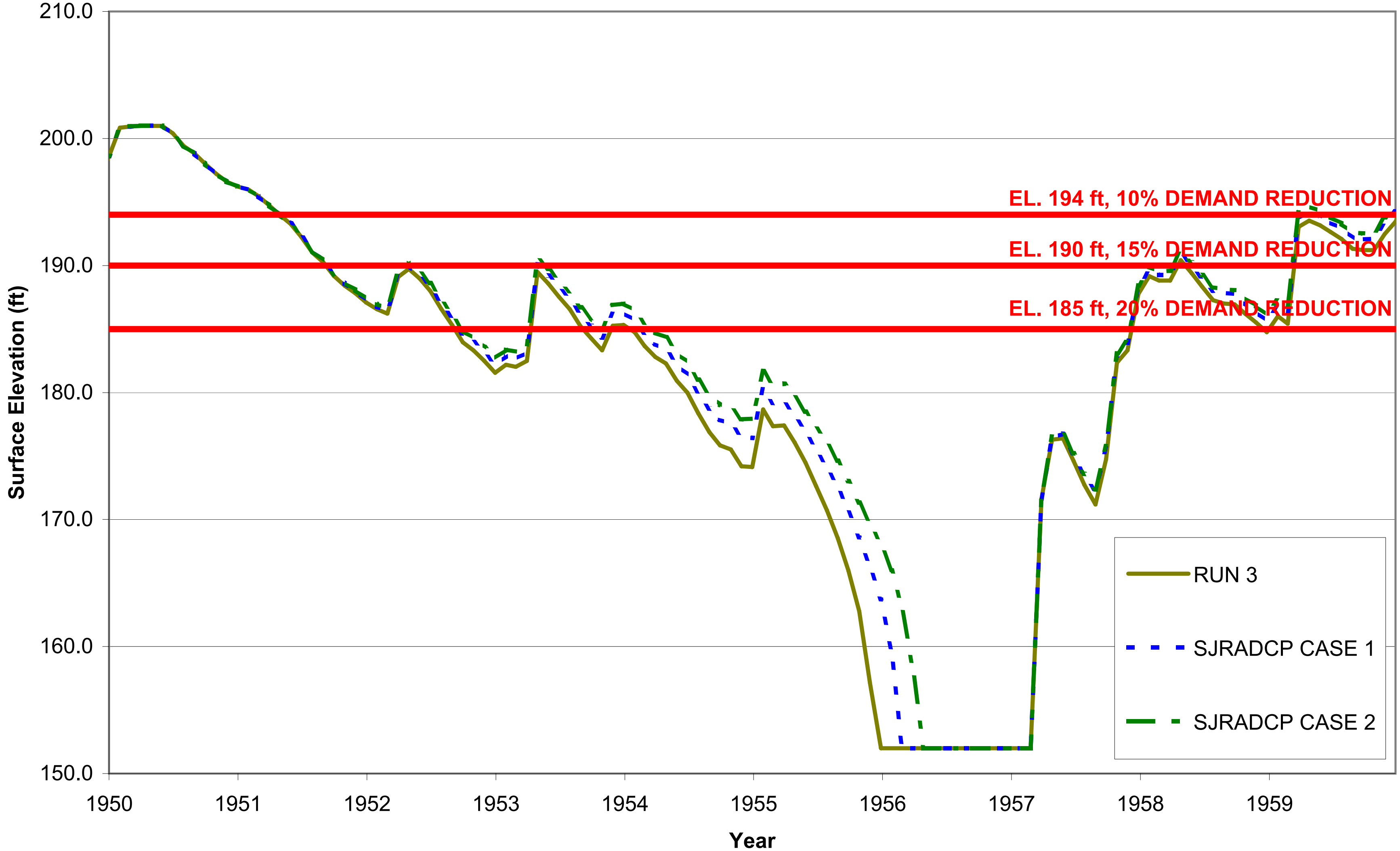
Figure B-9 Lake Conroe Elevations During Drought of Record (yr 2060 Storage Capacity) (SJRA Drought Contingency Plan)



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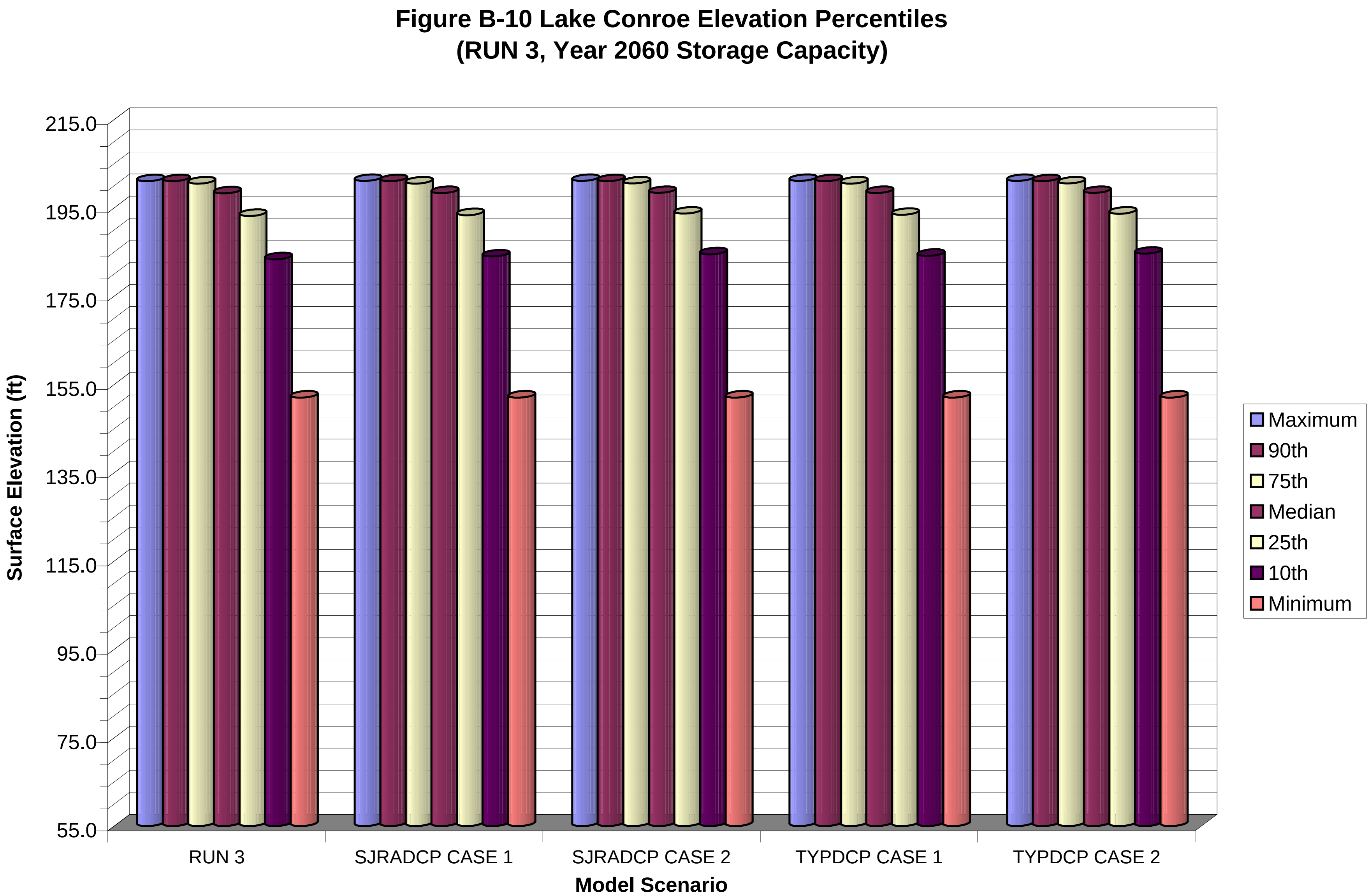
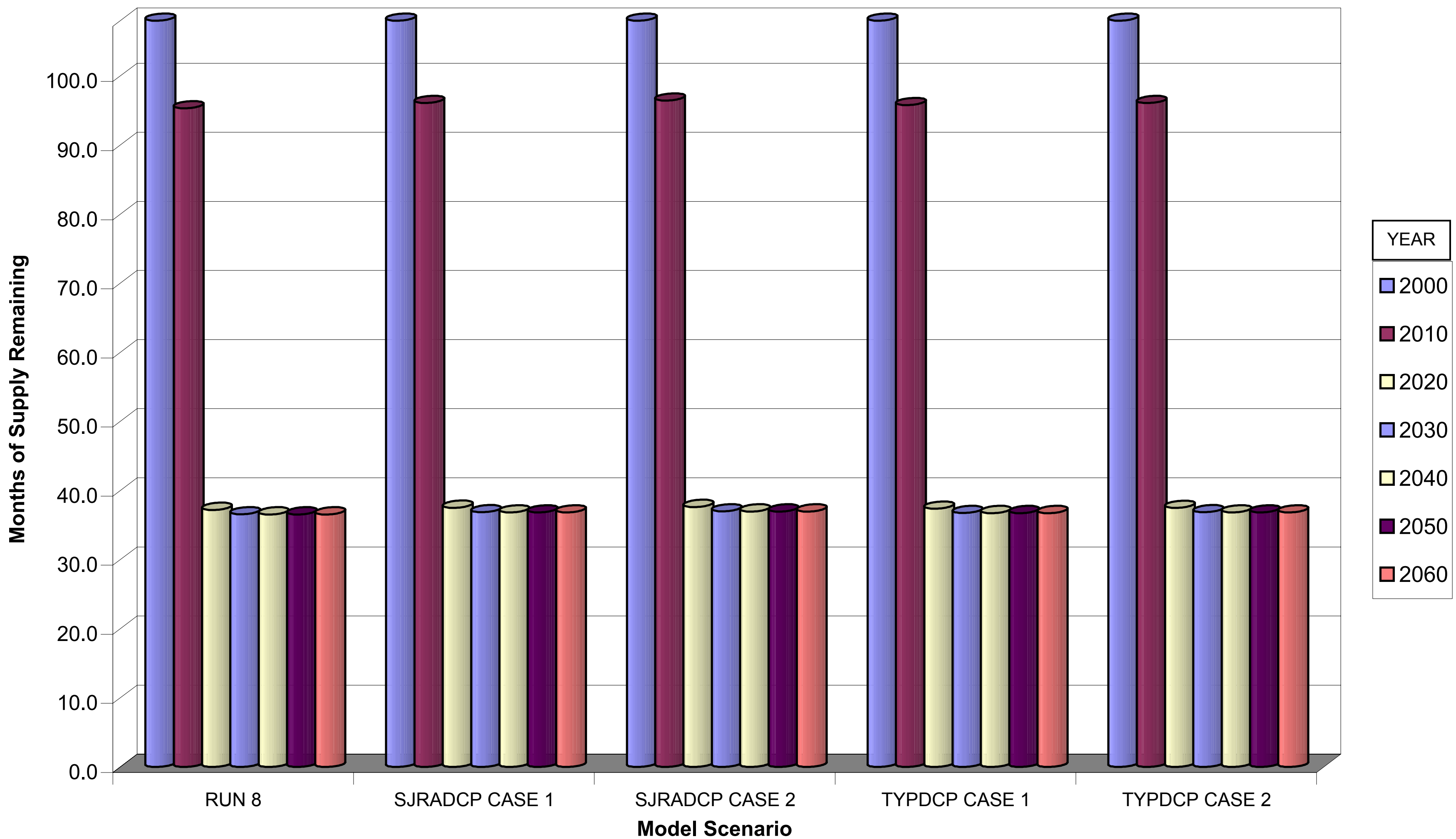


Figure B-10 Lake Conroe Elevation Percentiles
(RUN 3, Year 2060 Storage Capacity)
Surface Elevation (ft)
215.0
195.0
175.0
155.0
135.0
115.0
95.0
75.0
55.0
RUN 3
SJRADCP CASE 1
SJRADCP CASE 2
TYPDCP CASE 1
TYPDCP CASE 2
Model Scenario
Maximum
90th
75th
Median
25th
10th
Minimum

**Figure B-11 Lake Conroe
Remaining Supply during Drought of Record
(RUN 8, Year 2000 Storage Capacity)**



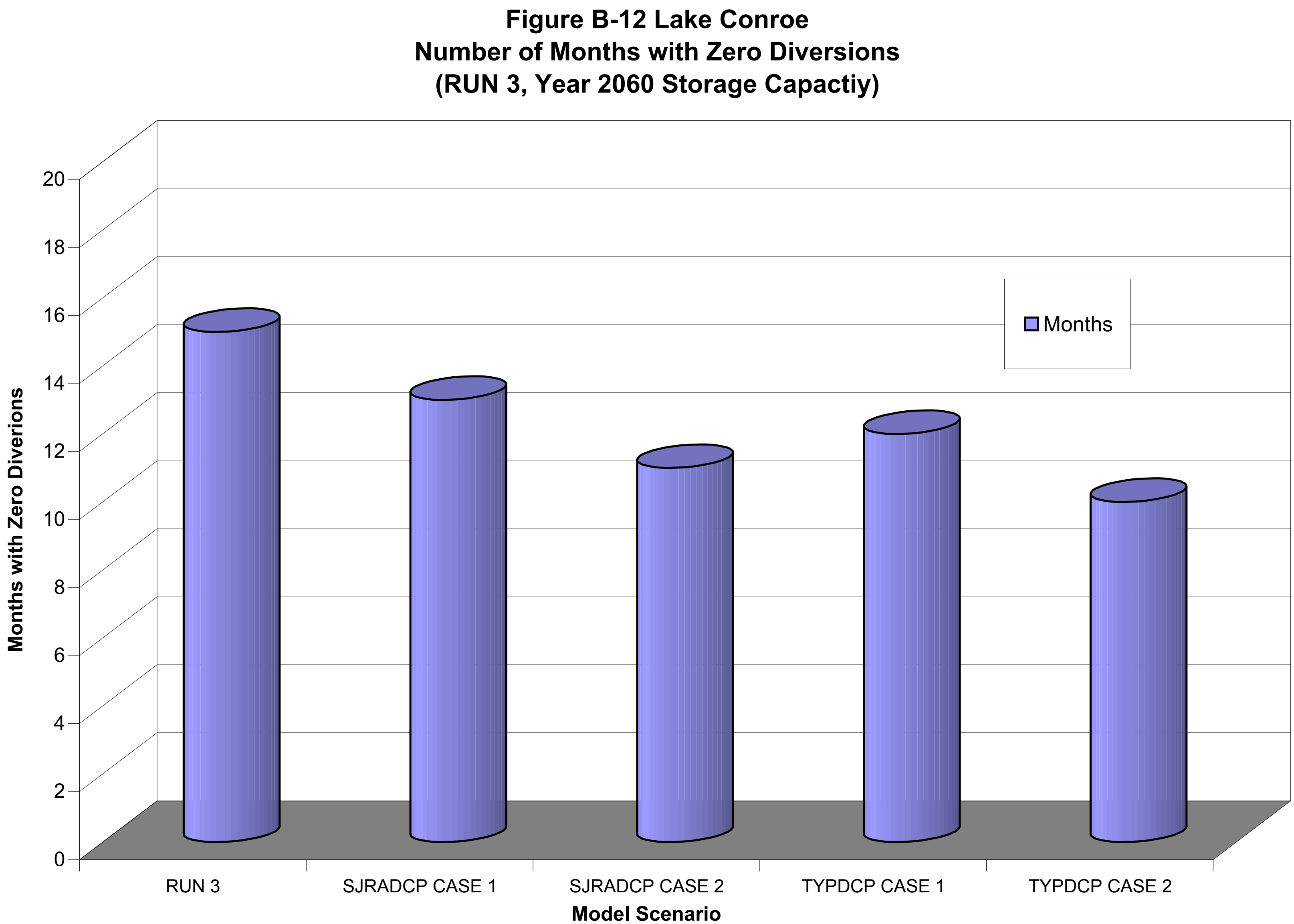


Figure B-12 Lake Conroe
Number of Months with Zero Diversions
(RUN 3, Year 2060 Storage Capactiy)
Months with Zero Diverions
0
2
4
6
8
10
12
14
16
18
20
Months
RUN 3
SJRADCP CASE 1
SJRADCP CASE 2
TYPDCP CASE 1
TYPDCP CASE 2
Model Scenario

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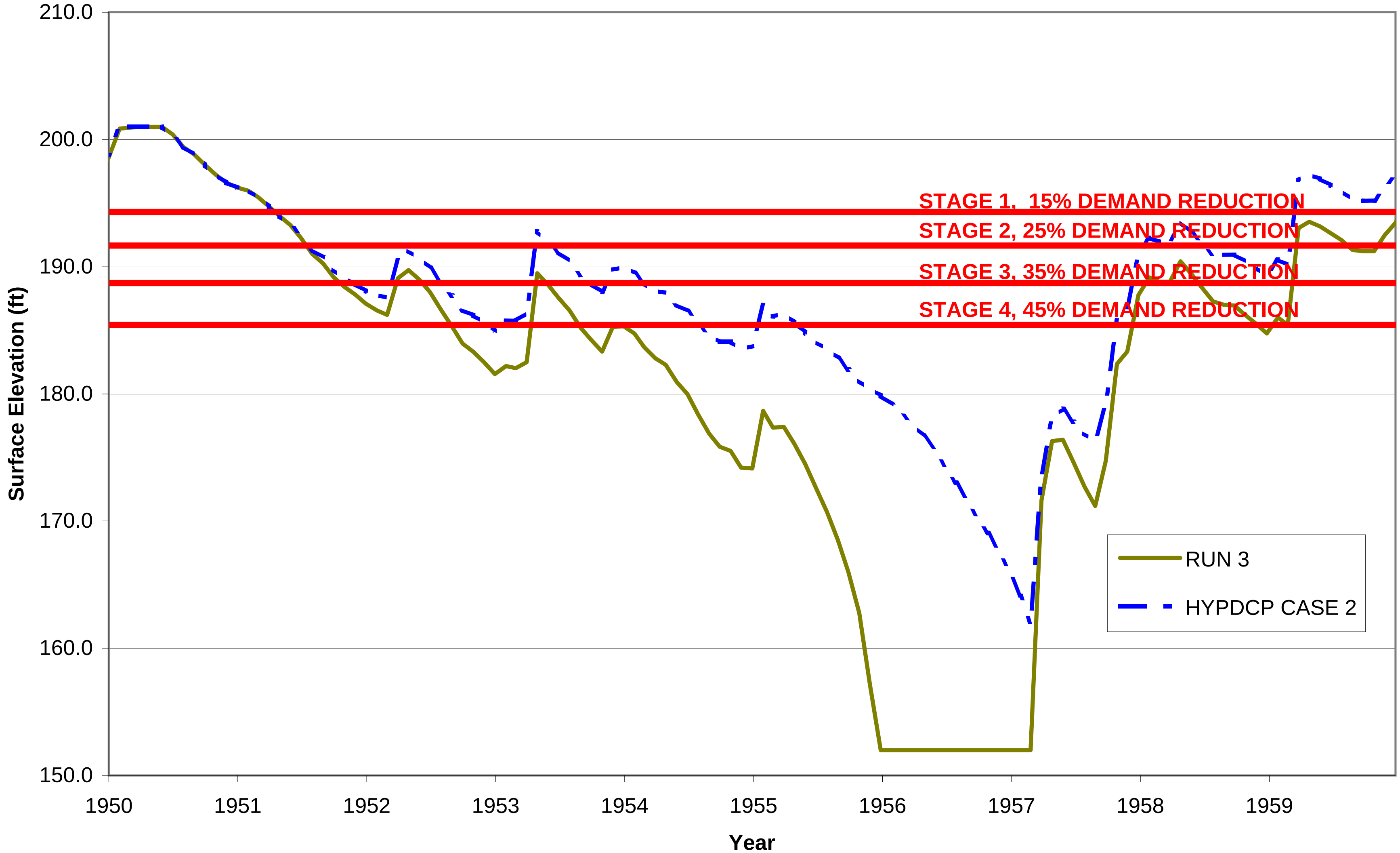
Figure B-13 Lake Conroe Elevations During Drought of Record
(yr 2060 Storage Capacity)
(Hypothetical Typical Drought Contingency Plan)



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APPENDIX C

Lake Houston

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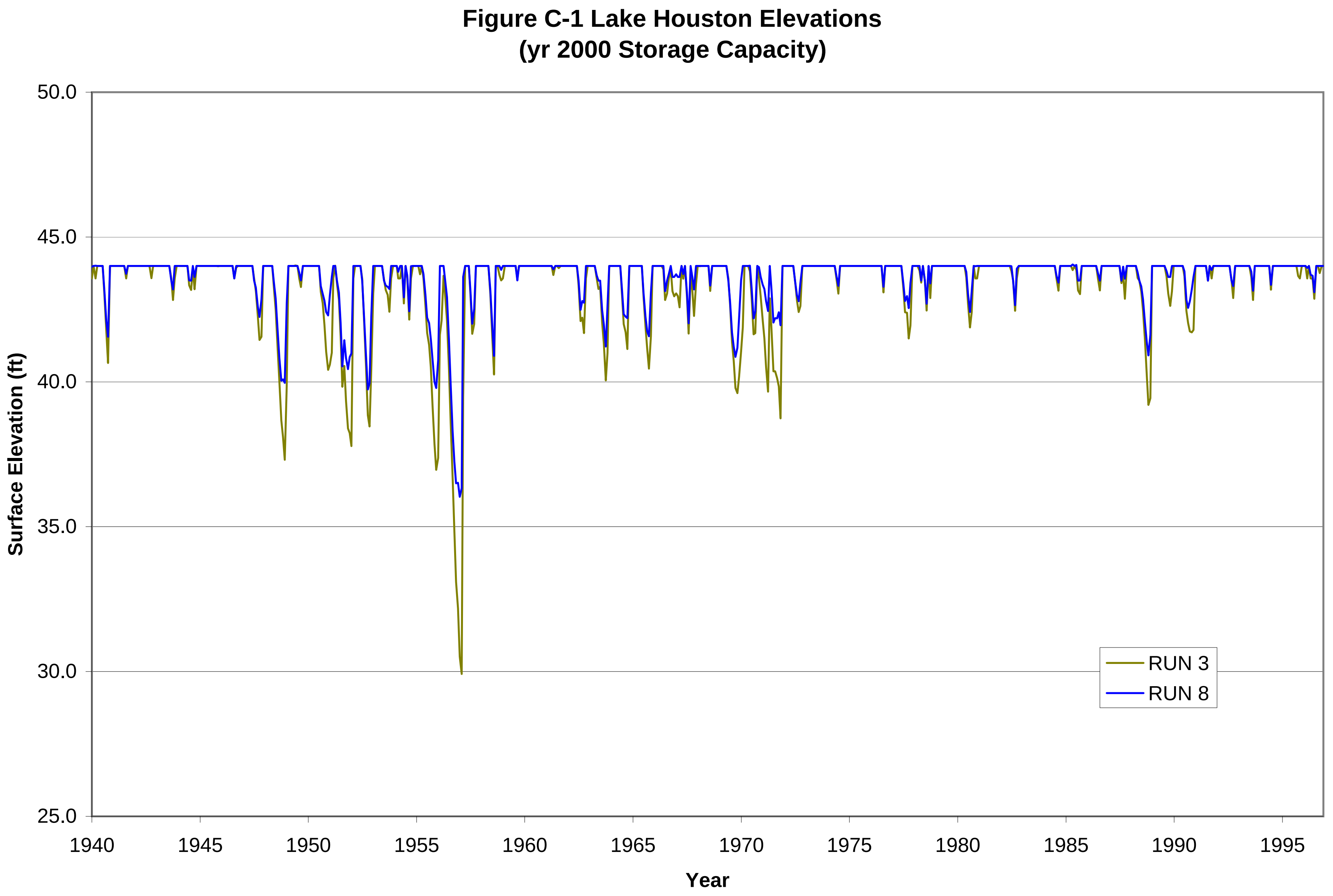


Figure C-1 Lake Houston Elevations
(yr 2000 Storage Capacity)
50.0
45.0
40.0
35.0
30.0
25.0
Surface Elevation (ft)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8

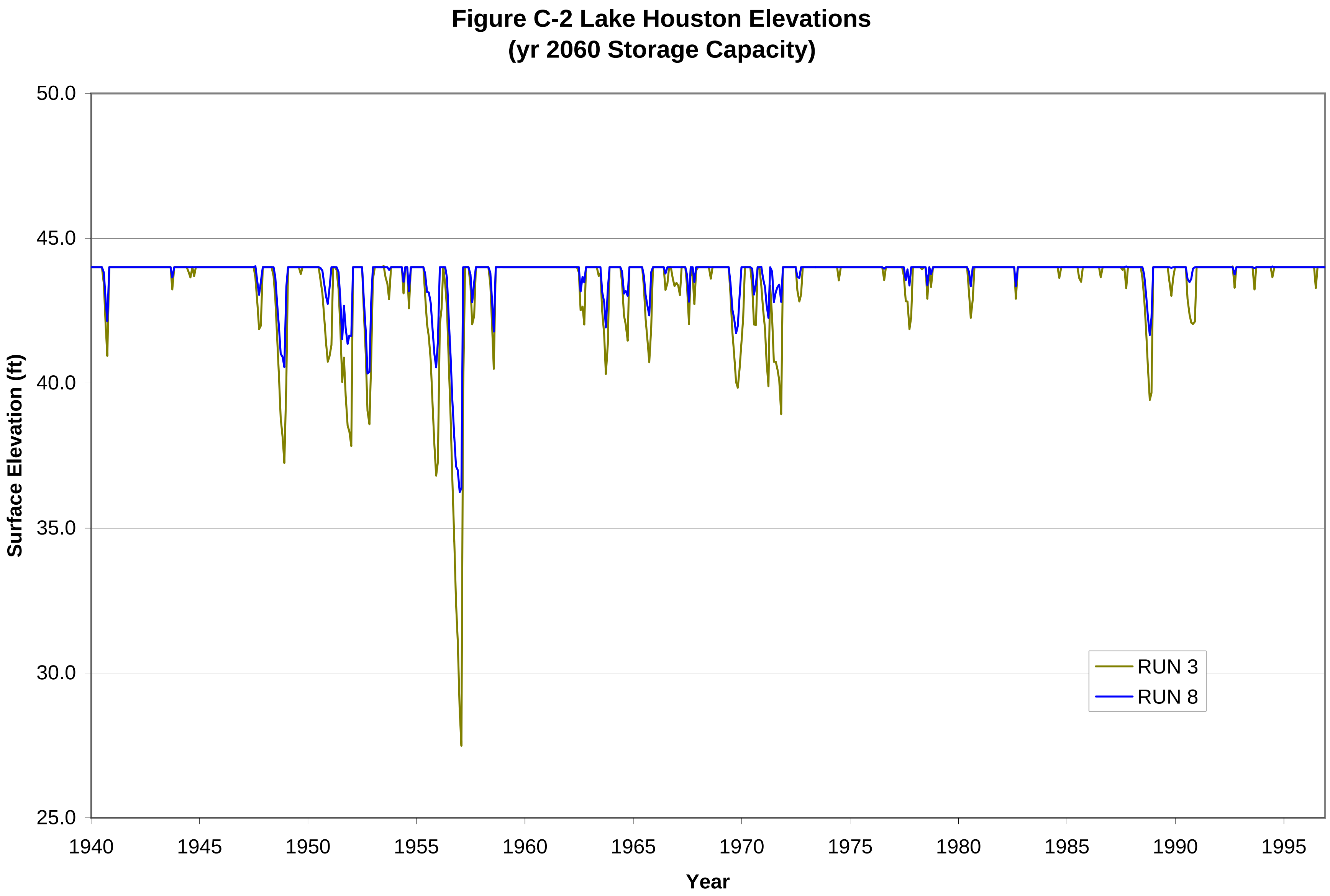
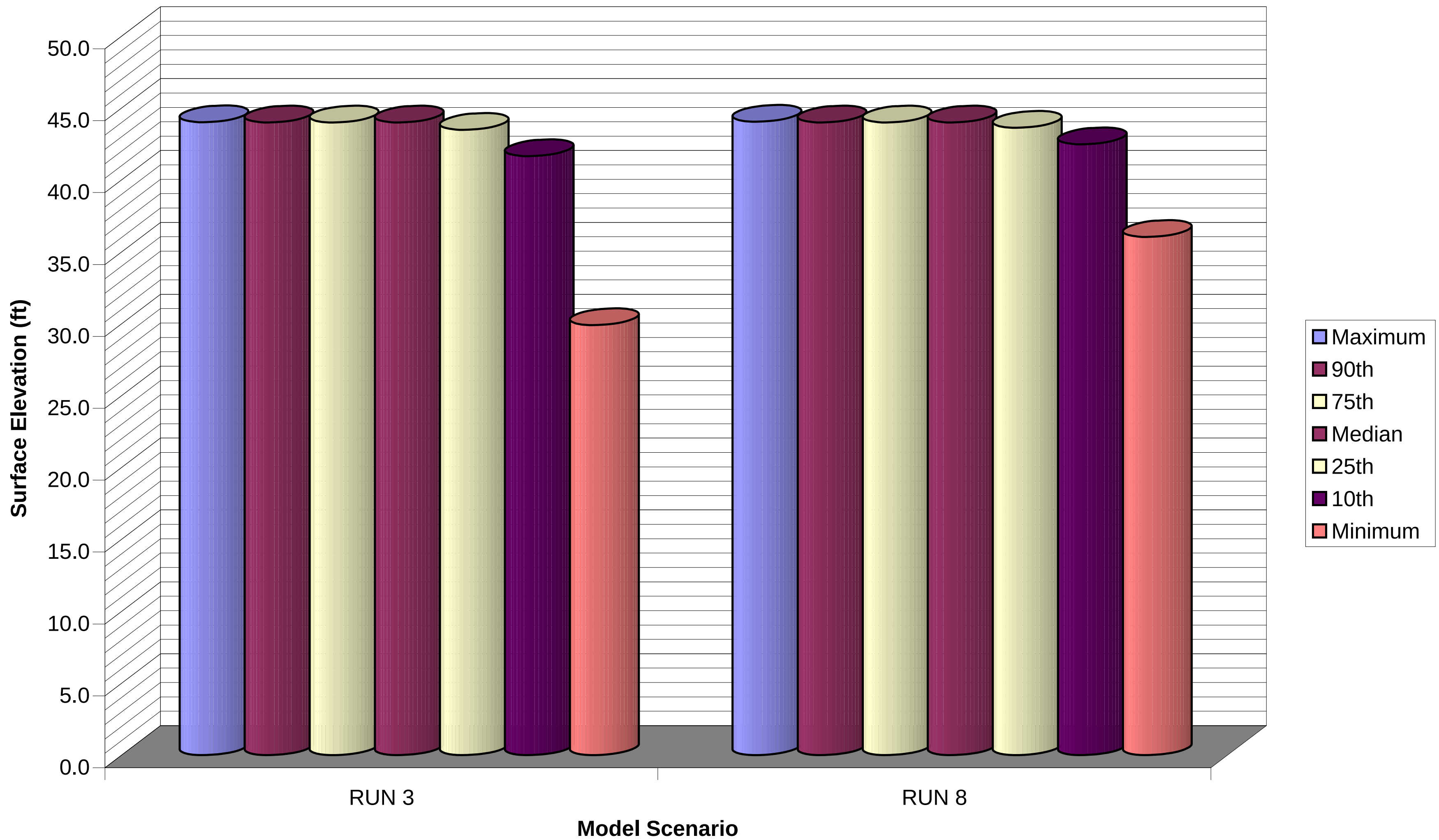


Figure C-2 Lake Houston Elevations
(yr 2060 Storage Capacity)
50.0
45.0
40.0
35.0
30.0
25.0
Surface Elevation (ft)
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Year
RUN 3
RUN 8

Figure C-3 Lake Houston Elevation Percentiles (RUN 8, Year 2000 Storage Capacity)



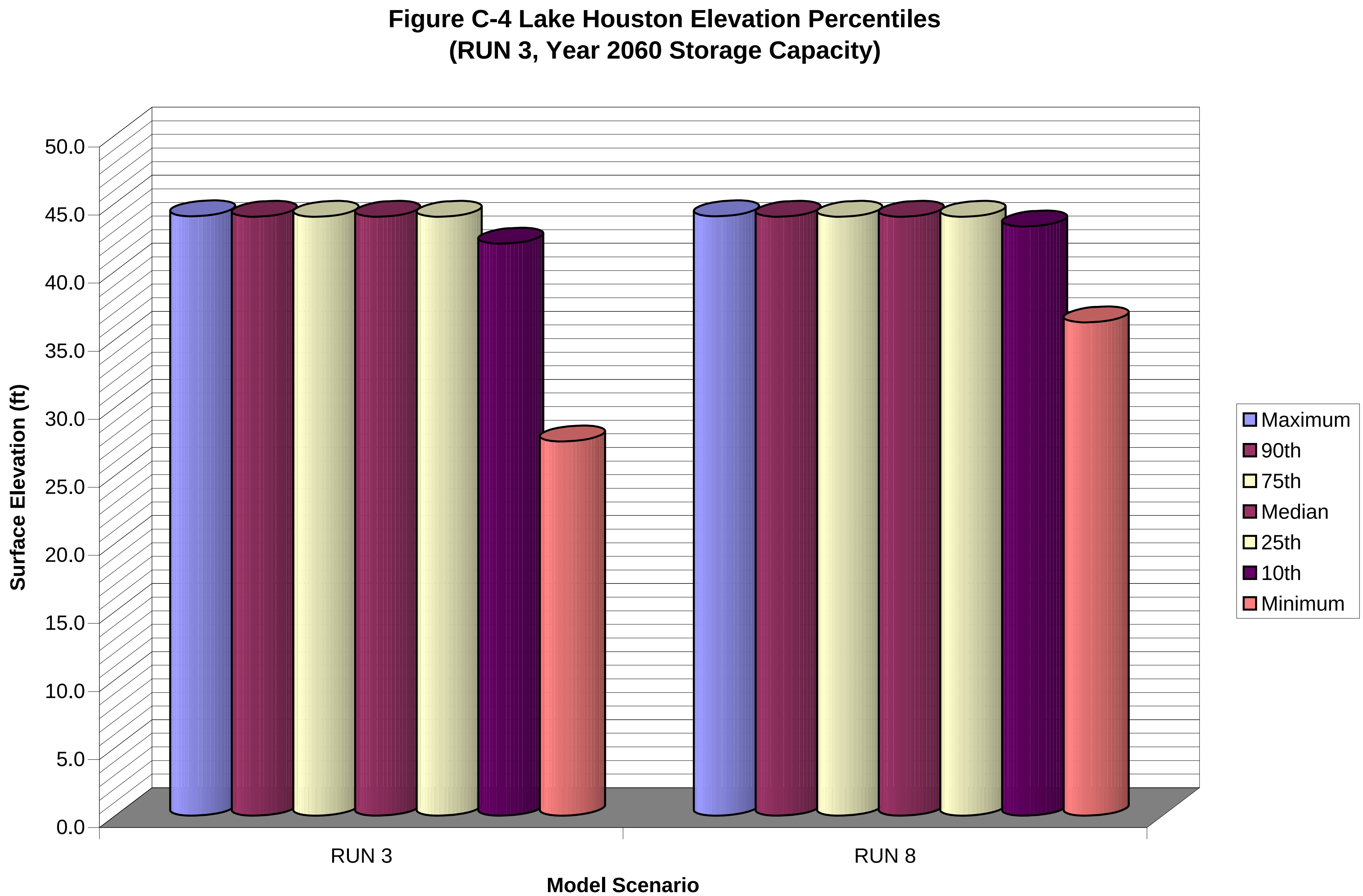


Figure C-4 Lake Houston Elevation Percentiles
(RUN 3, Year 2060 Storage Capacity)
Surface Elevation (ft)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
RUN 3
RUN 8
Model Scenario
Maximum
90th
75th
Median
25th
10th
Minimum

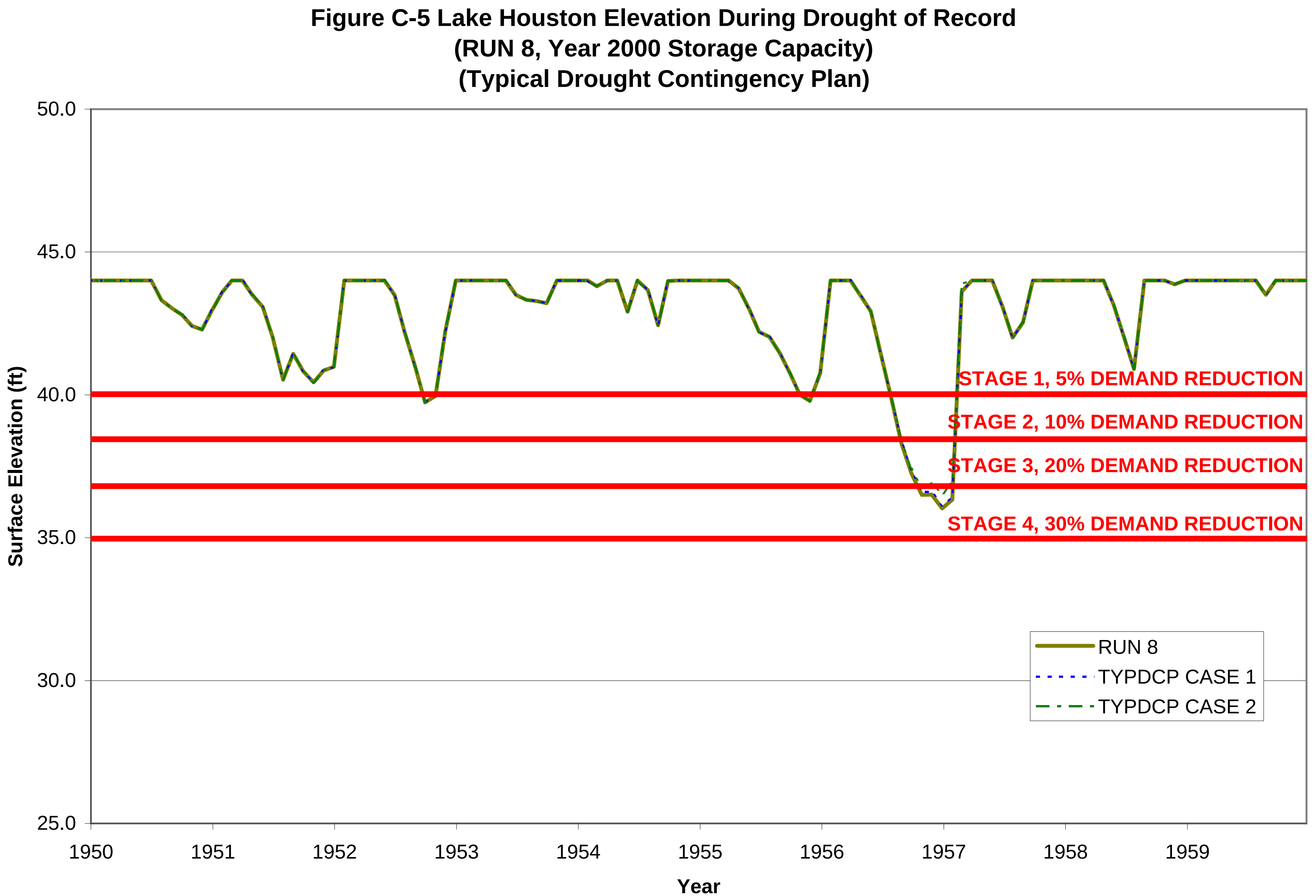
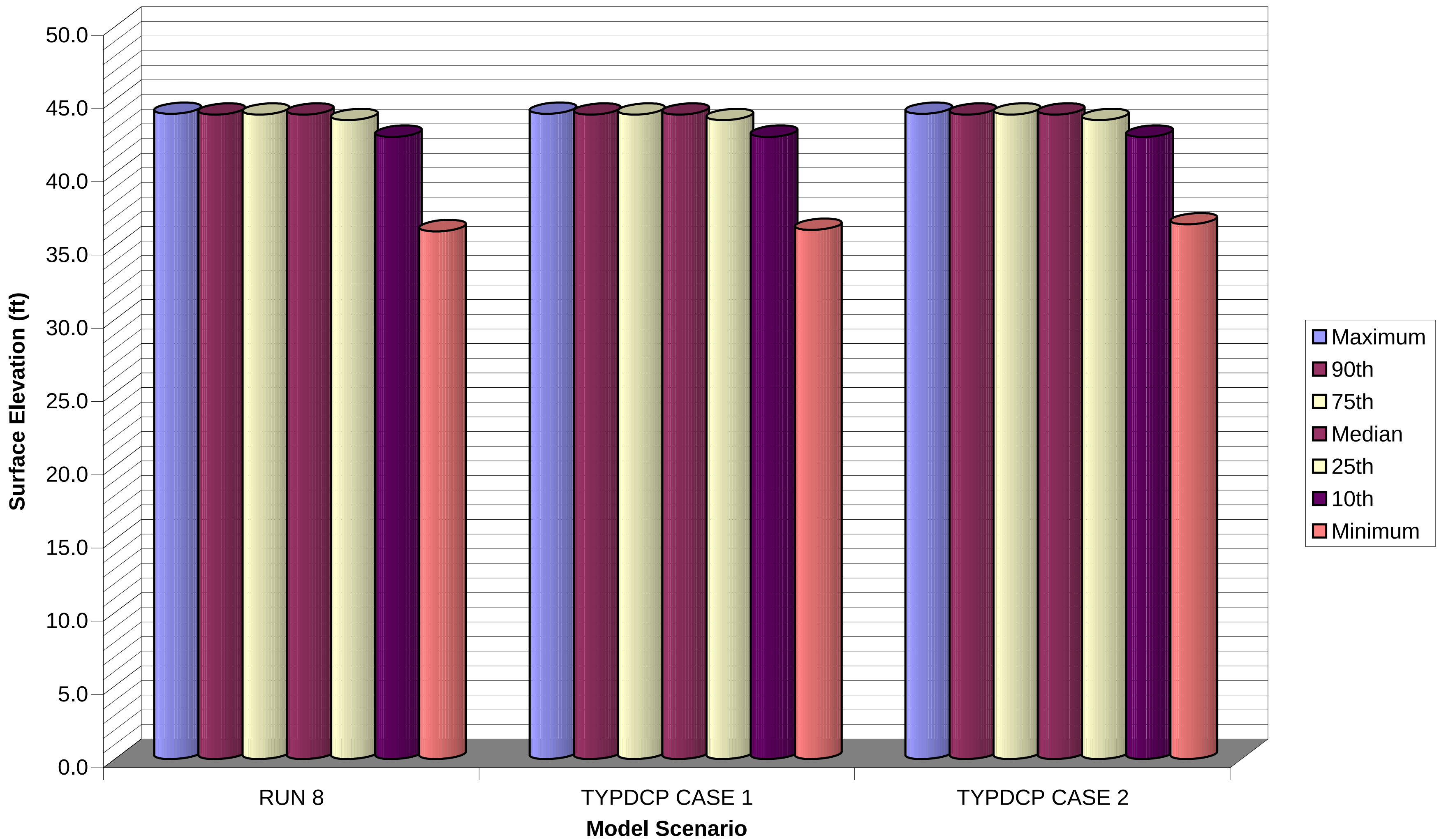


Figure C-5 Lake Houston Elevation During Drought of Record
(RUN 8, Year 2000 Storage Capacity)
(Typical Drought Contingency Plan)
Surface Elevation (ft)
50.0
45.0
40.0
35.0
30.0
25.0
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
RUN 8
TYPDCP CASE 1
TYPDCP CASE 2
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year

Figure C-6 Lake Houston Elevation Percentiles
RUN 8, Year 2000 Storage Capacity



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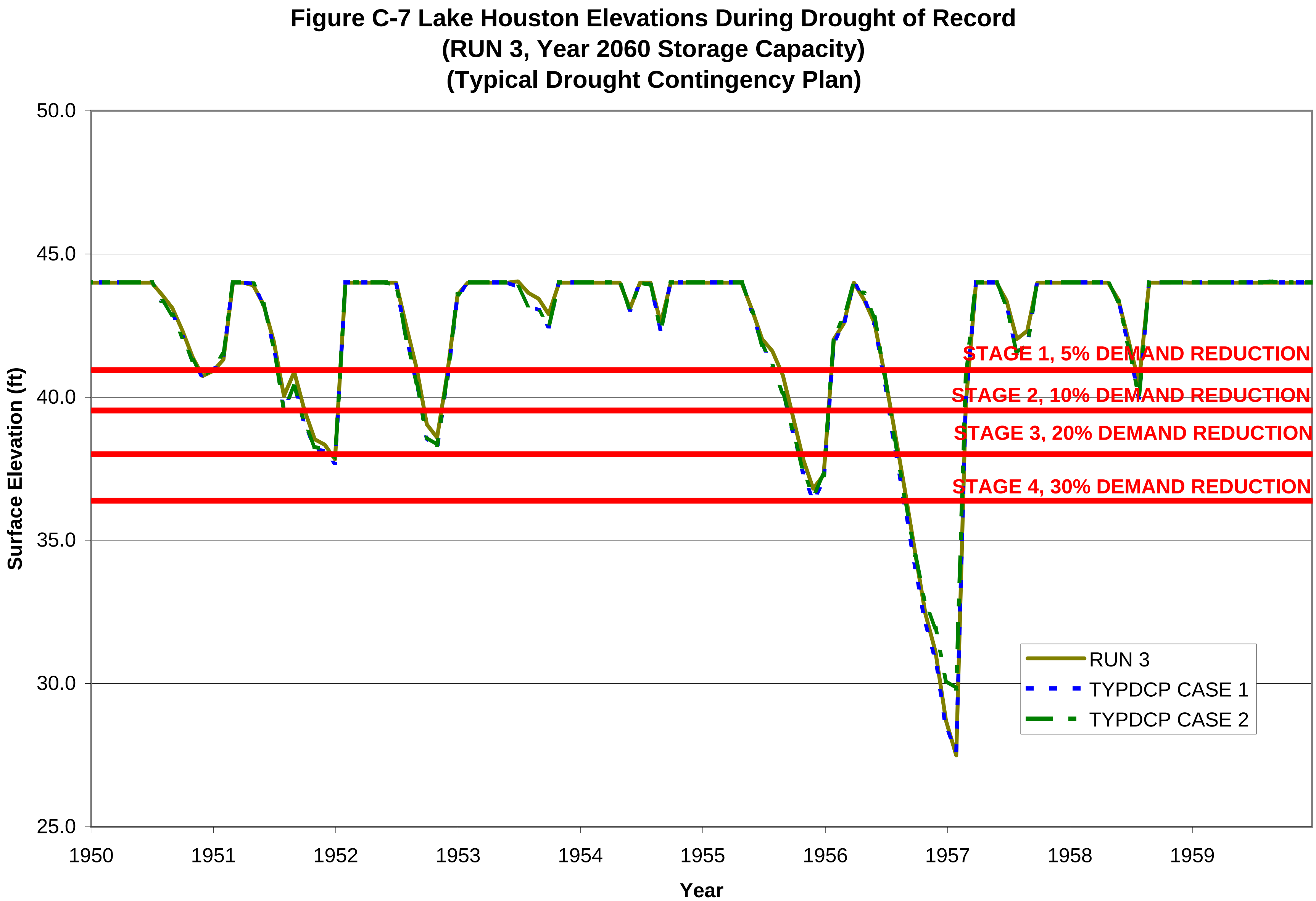


Figure C-7 Lake Houston Elevations During Drought of Record
(RUN 3, Year 2060 Storage Capacity)
(Typical Drought Contingency Plan)
Surface Elevation (ft)
50.0
45.0
40.0
35.0
30.0
25.0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
RUN 3
TYPDCP CASE 1
TYPDCP CASE 2

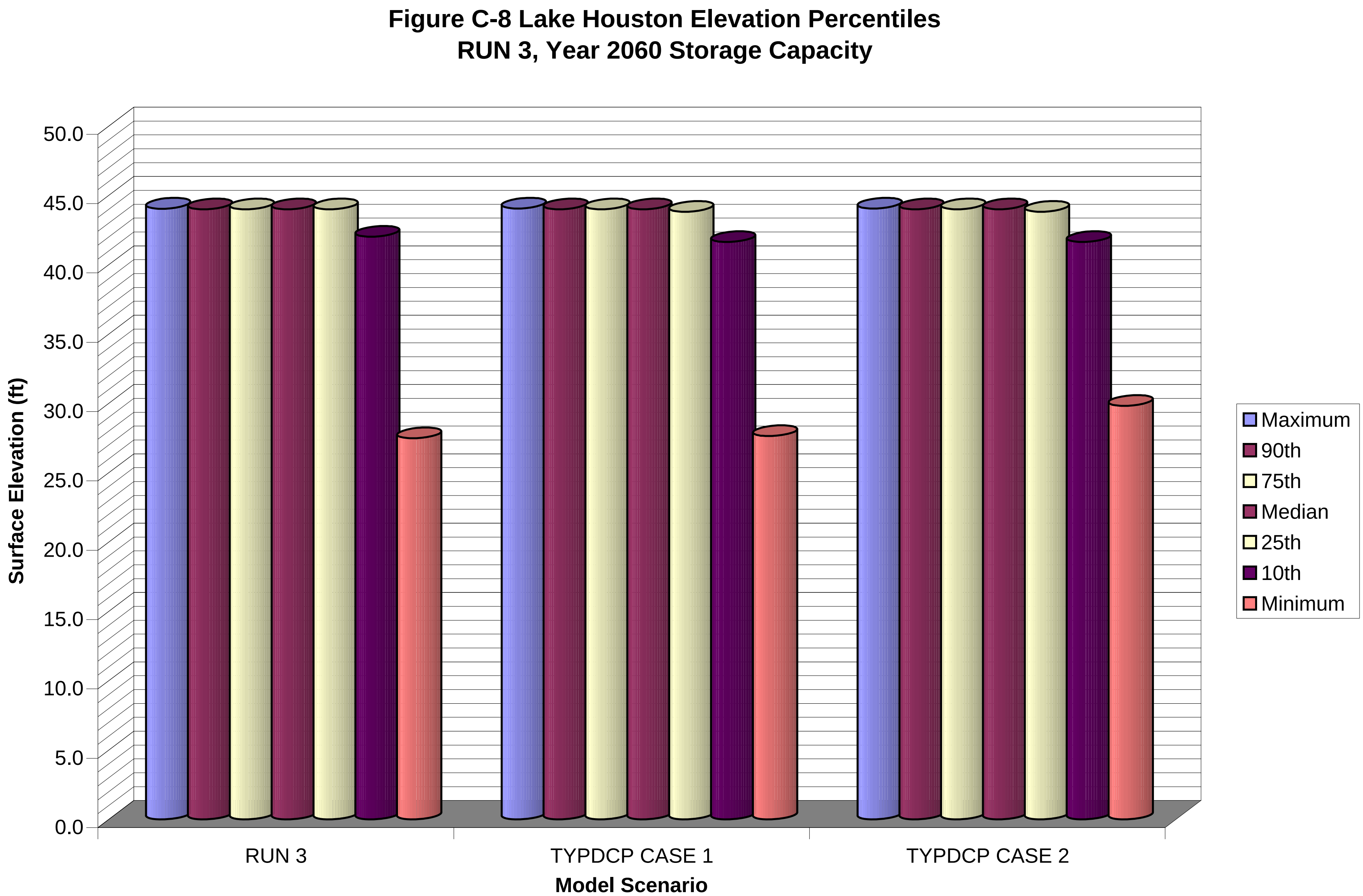


Figure C-8 Lake Houston Elevation Percentiles
RUN 3, Year 2060 Storage Capacity
Surface Elevation (ft)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
RUN 3
TYPDCP CASE 1
TYPDCP CASE 2
Model Scenario
Maximum
90th
75th
Median
25th
10th
Minimum

Figure C-9 Lake Houston
Remaining Supply during Drought of Record
(RUN 8, Year 2000 Storage Capacity)

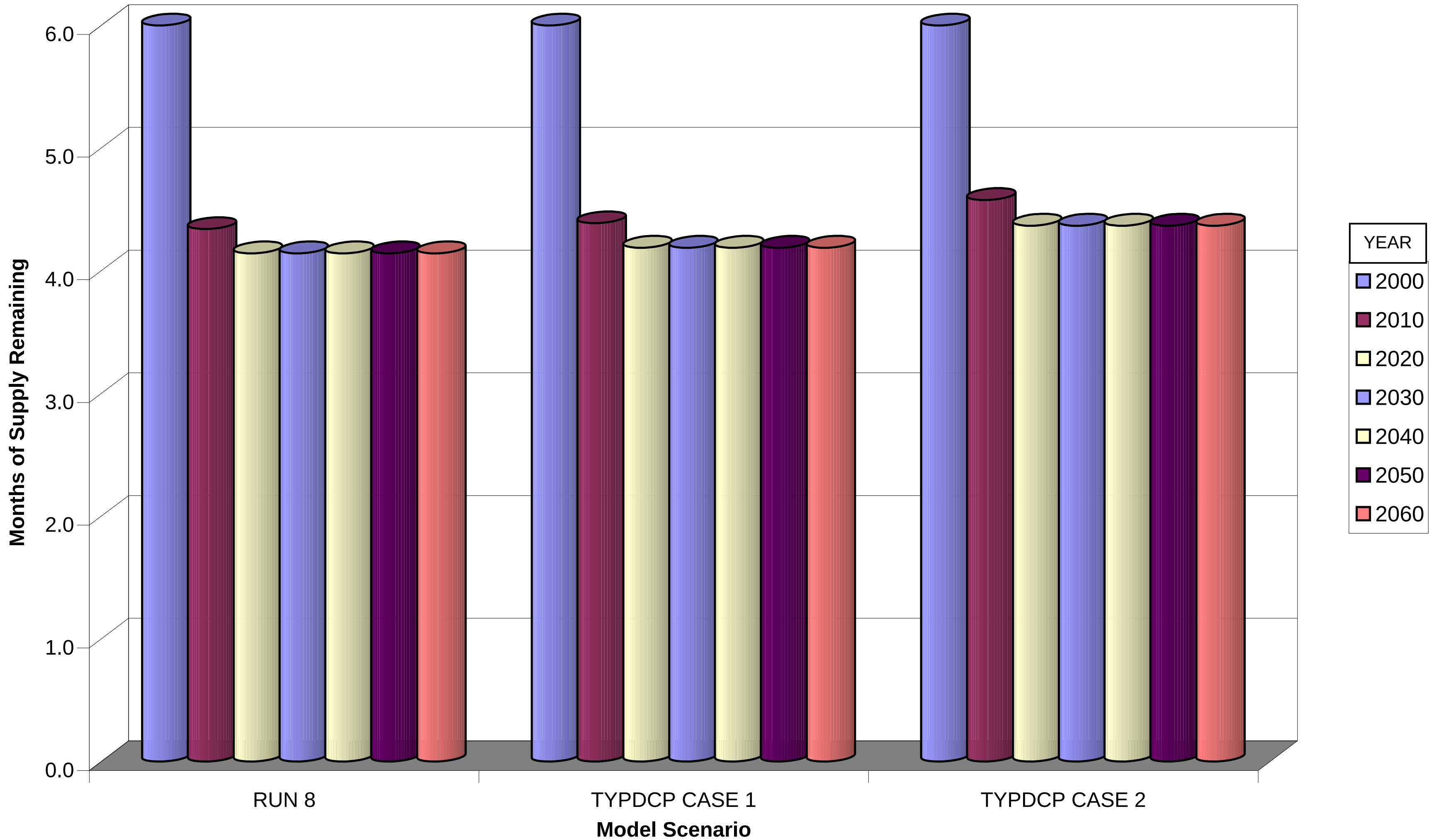
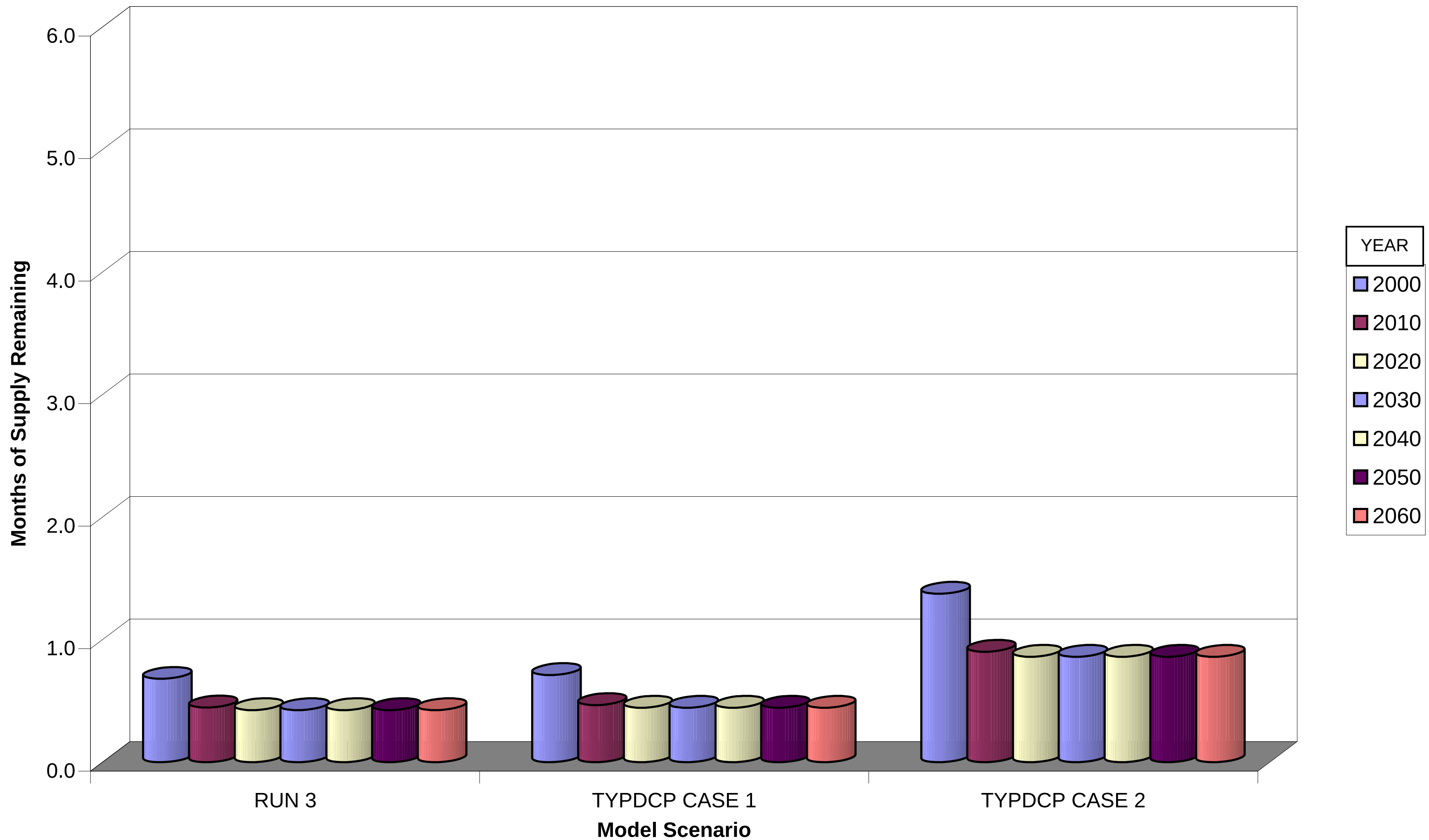


Figure C-10 Lake Houston
Remaining Supply during Drought of Record
(RUN 3, Year 2060 Storage Capacity)



APPENDIX D

Allens Creek Reservoir

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**Figure D-1 Allens Creek Storage
(yr 2000 Storage Capacity)**

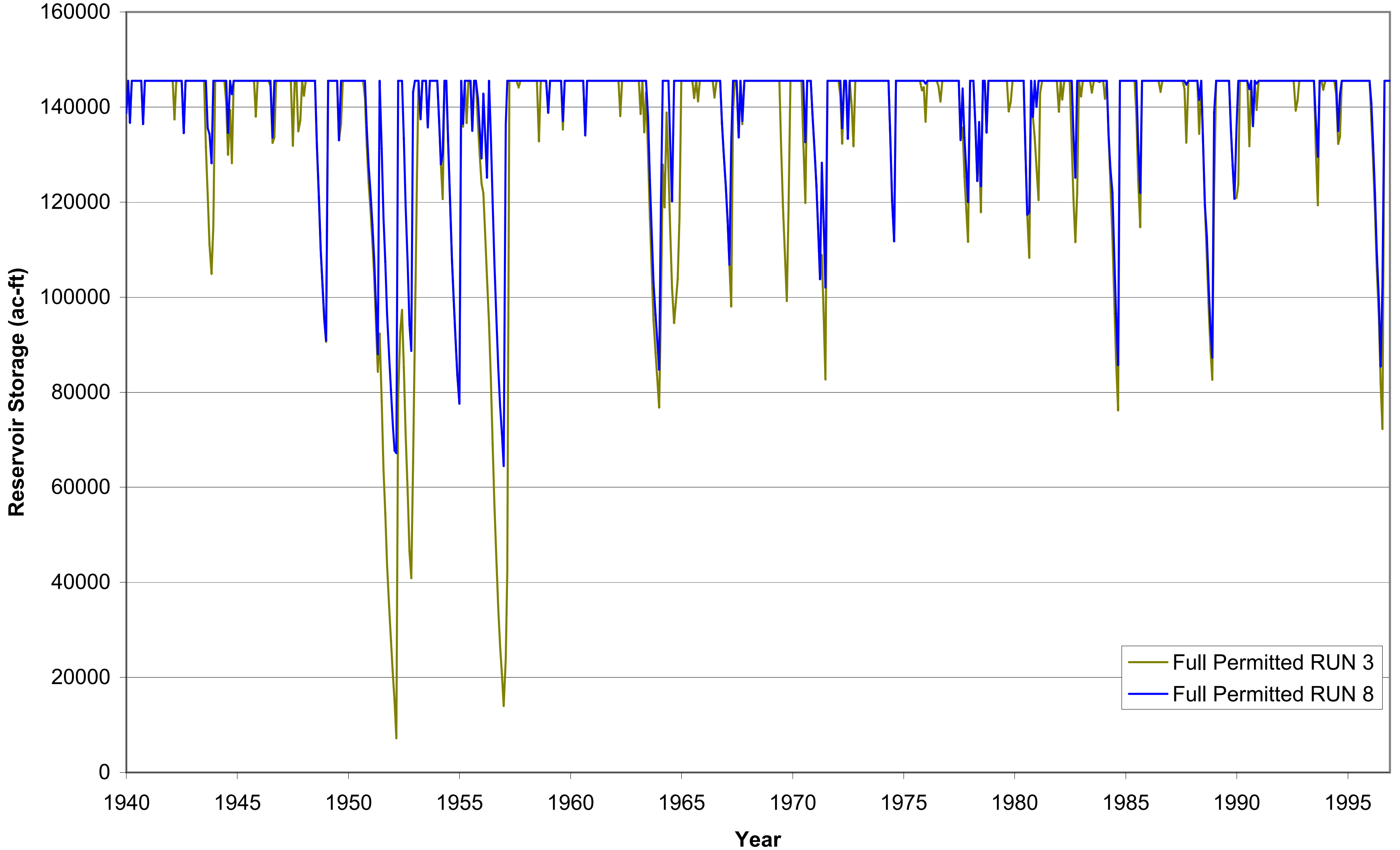
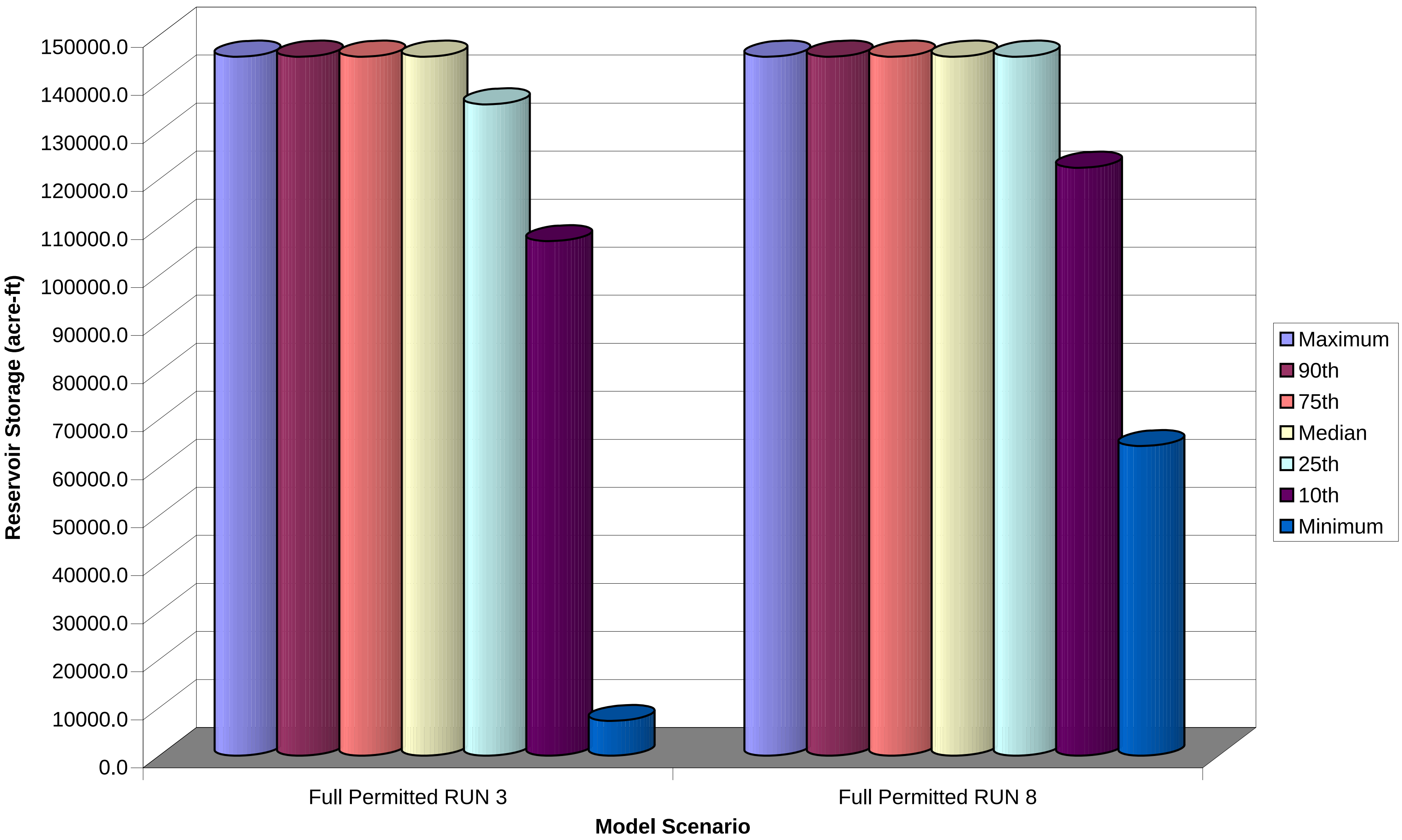


Figure D-2 Allens Creek Storage Percentiles



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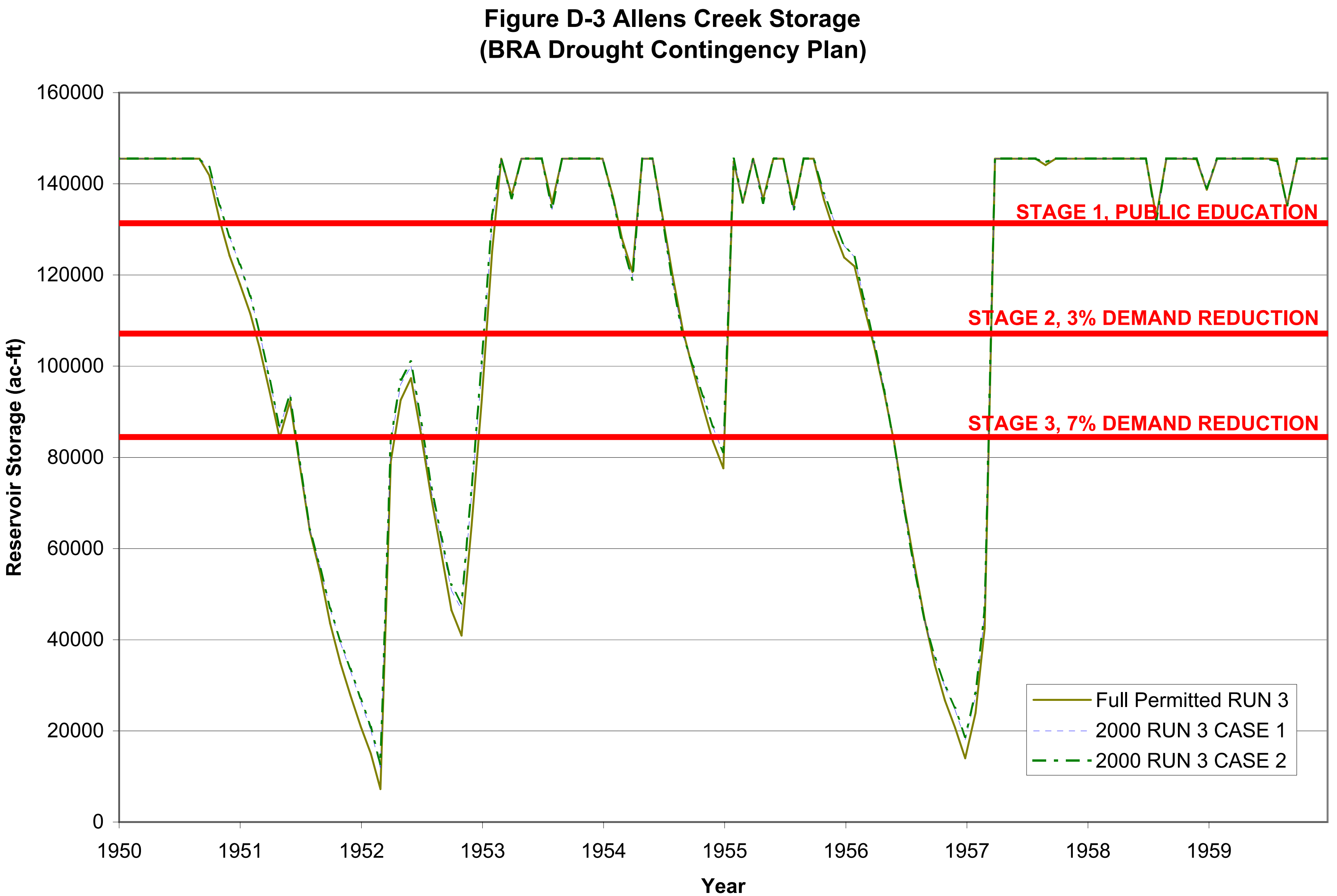
Figure D-3 Allens Creek Storage
(BRA Drought Contingency Plan)
Reservoir Storage (ac-ft)
160000
140000
120000
100000
80000
60000
40000
20000
0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, PUBLIC EDUCATION
STAGE 2, 3% DEMAND REDUCTION
STAGE 3, 7% DEMAND REDUCTION
Full Permitted RUN 3
2000 RUN 3 CASE 1
2000 RUN 3 CASE 2

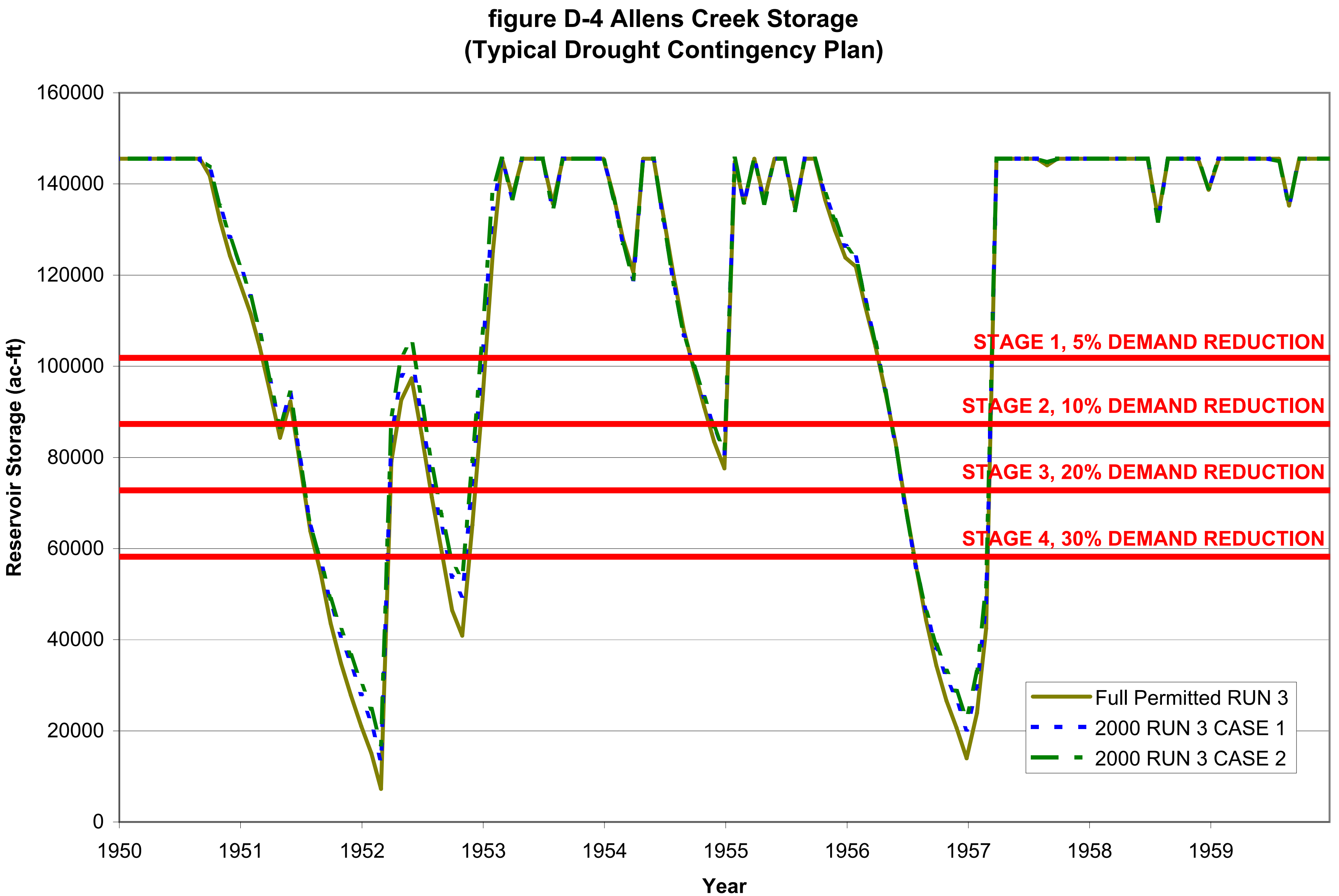
figure D-4 Allens Creek Storage
(Typical Drought Contingency Plan)
160000
140000
120000
100000
80000
60000
40000
20000
0
Reservoir Storage (ac-ft)
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
Year
STAGE 1, 5% DEMAND REDUCTION
STAGE 2, 10% DEMAND REDUCTION
STAGE 3, 20% DEMAND REDUCTION
STAGE 4, 30% DEMAND REDUCTION
Full Permitted RUN 3
2000 RUN 3 CASE 1
2000 RUN 3 CASE 2

**Figure D-5 Allens Creek Storage
(BRA Drought Contingency Plan)**

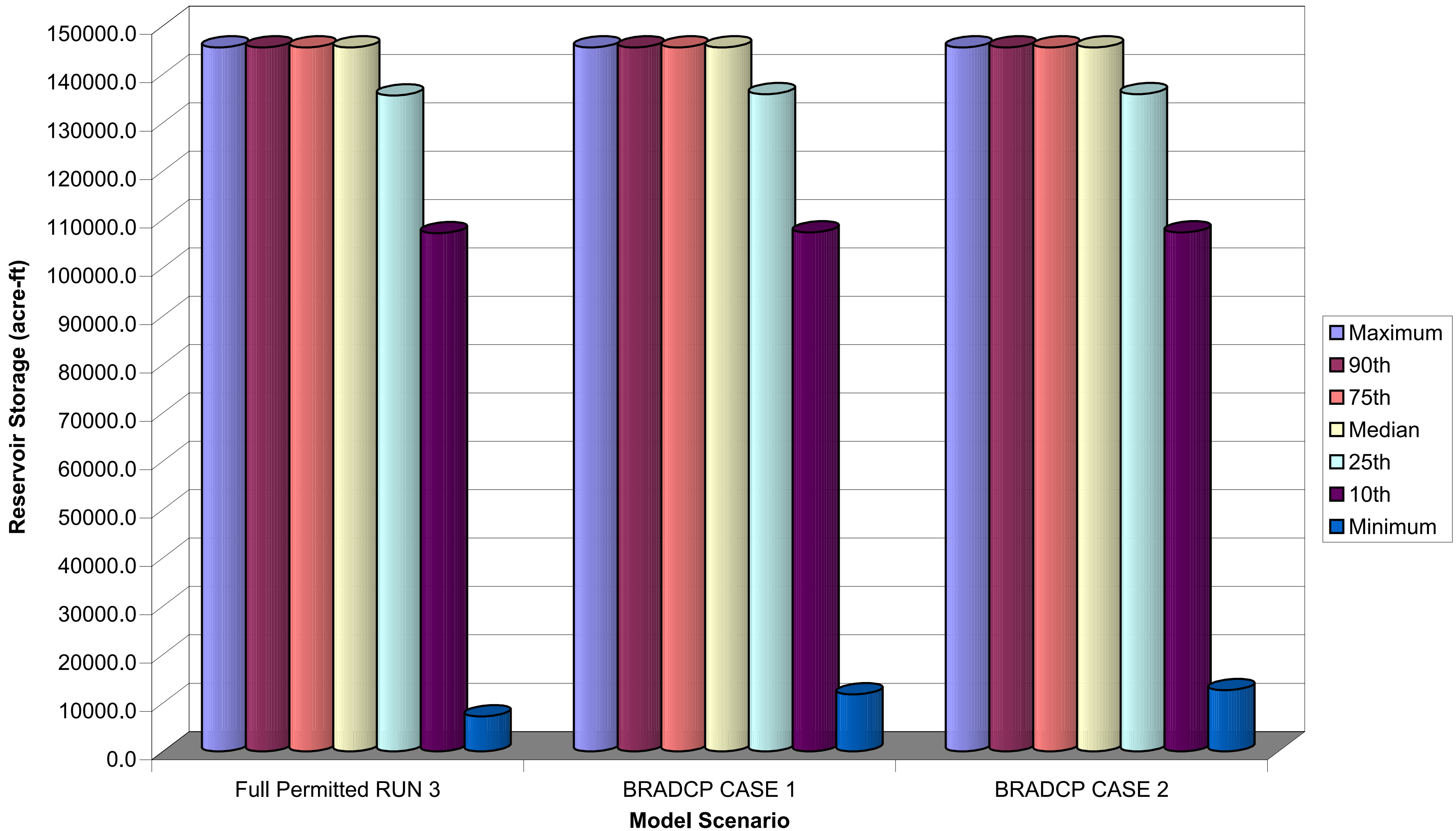

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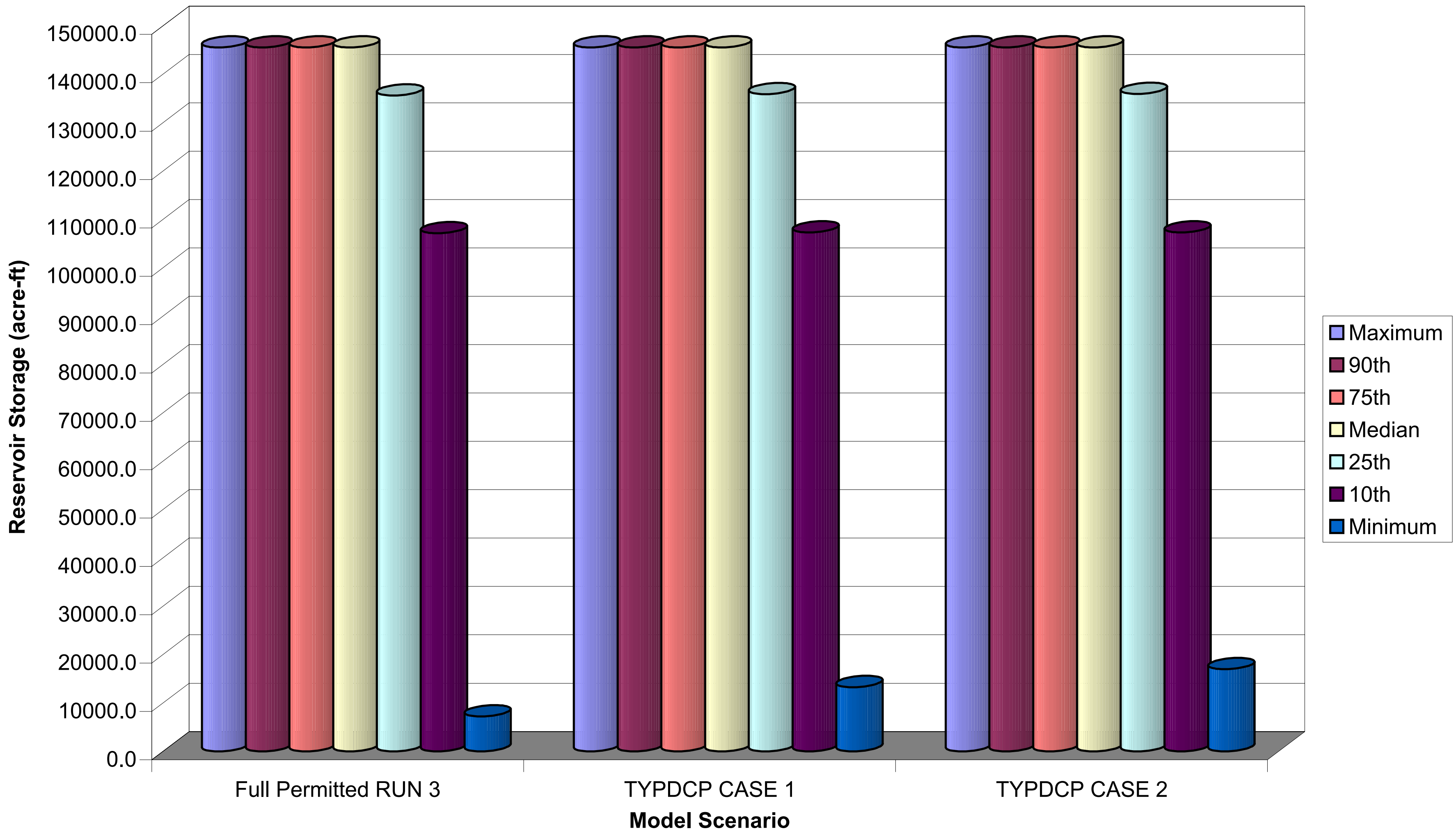
Figure D-6 Allens Creek Storage
(Typical Drought Contingency Plan)



10/28/2008

Figure D-7 Allens Creek
Remaining Supply during Drought of Record
(BRA Drought Contingency Plan)

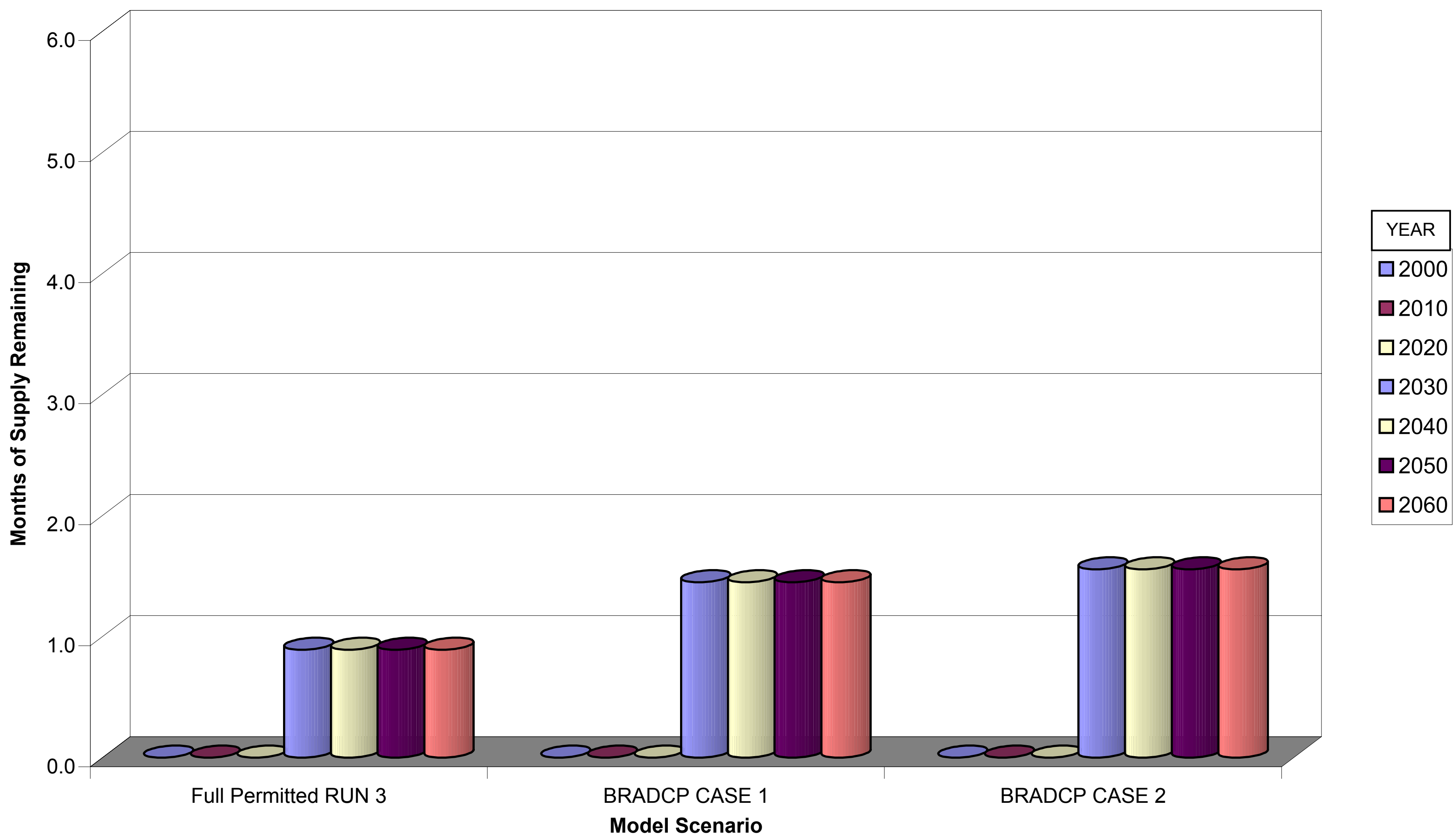


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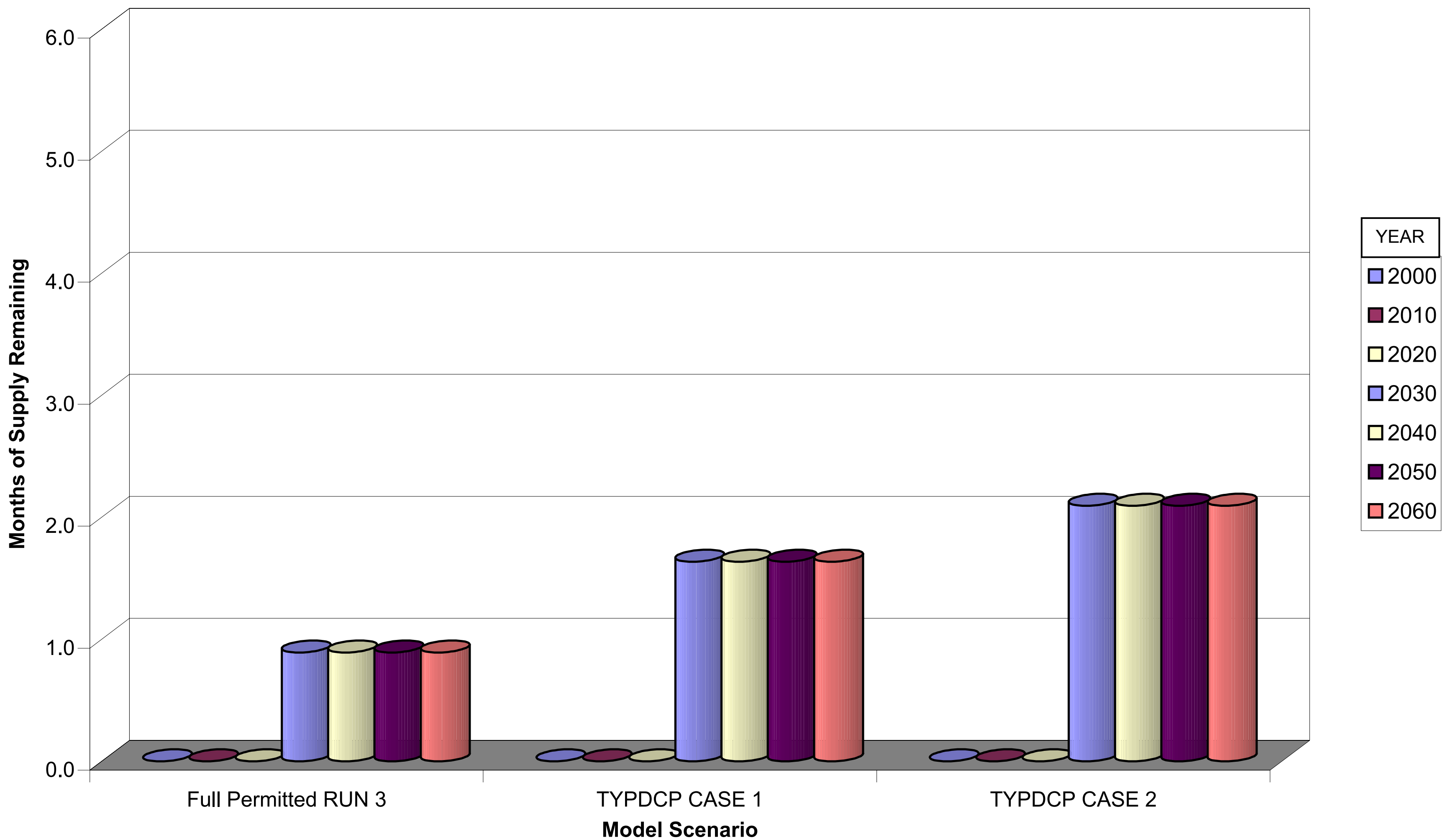
Figure D-8 Allens Creek
Remaining Supply during Drought of Record
(Typical Drought Contingency Plan)



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APPENDIX E

WUG Demand Reduction Table

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wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
BAYTOWN	80042000	Demand	10,938	11,092	11,151	11,261	11,344	11,587	11,914	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	8,654	8,776	8,823	8,910	8,975	9,168	9,426	
BEACH CITY	80822000	Demand	228	314	413	501	579	662	747	Livingston
		Reduction	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	228	248	327	396	458	524	591	
BELLAIRE	80046000	Demand	3,452	3,734	3,993	4,254	4,527	4,817	5,131	Livingston, Houston
		Reduction	16.40%	16.40%	17.60%	17.60%	18.20%	18.20%	18.20%	
		DOR Demand	2,885	3,121	3,289	3,504	3,705	3,942	4,199	
BIG OAKS MUD	84020000	Demand	292	581	875	1,246	1,614	2,110	2,677	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	292	581	875	1,064	1,379	1,803	2,287	
BLUE BELL MANOR UTILITY COMPANY	84026000	Demand	581	572	563	555	546	540	540	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	581	572	445	439	432	427	427	
BRITMOORE UTILITIES	84036000	Demand	390	471	550	626	705	783	864	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	390	471	435	495	558	620	684	
BUNKER HILL VILLAGE	80085000	Demand	1,478	1,504	1,491	1,479	1,466	1,462	1,462	Livingston, Houston
		Reduction	18.70%	18.70%	18.70%	18.70%	18.70%	18.70%	18.70%	
		DOR Demand	1,202	1,223	1,212	1,203	1,192	1,189	1,189	
CANDLELIGHT HILLS SUBDIVISION	84043000	Demand	368	451	530	610	691	770	853	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	368	451	419	483	547	609	675	
CHIMNEY HILL MUD	84053000	Demand	557	668	646	625	618	611	611	Livingston, Houston
		Reduction	0.00%	0.00%	20.90%	18.30%	18.30%	18.30%	18.30%	
		DOR Demand	557	668	511	511	505	499	499	
CINCO MUD #2	84058000	Demand	1,085	2,190	3,325	4,735	6,158	8,052	10,215	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	1,085	2,190	3,325	4,045	5,261	6,879	8,727	
CINCO MUD #6	84059000	Demand	296	576	859	1,196	1,529	1,952	2,425	Livingston, Allens Creek
		Reduction	0.00%	0.00%	20.90%	16.00%	16.50%	16.50%	16.50%	
		DOR Demand	296	576	680	1,005	1,277	1,630	2,025	
CINCO MUD #7	84060000	Demand	531	1,065	1,612	2,295	2,980	3,897	4,944	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	531	1,065	1,612	1,961	2,546	3,329	4,224	
CINCO MUD #9	84062000	Demand	814	1,608	2,415	3,401	4,386	5,673	7,131	Livingston, Allens Creek
		Reduction	0.00%	0.00%	20.90%	15.20%	15.40%	15.40%	15.40%	
		DOR Demand	814	1,608	1,911	2,885	3,709	4,797	6,030	
CLEAR BROOK CITY MUD	84063000	Demand	902	1,003	1,089	1,189	1,281	1,384	1,503	Allens Creek
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	714	794	862	941	1,014	1,095	1,189	
CONROE	80130000	Demand	7,175	9,334	10,611	13,190	16,310	20,406	25,281	Houston
		Reduction	0.00%	8.90%	8.90%	8.90%	8.90%	8.90%	8.90%	
		DOR Demand	7,175	8,501	9,664	12,013	14,855	18,586	23,026	
CONSUMERS WATER INC	84072000	Demand	433	609	761	952	1,133	1,361	1,604	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	433	609	602	753	896	1,077	1,269	
CORNERSTONES MUD	84073000	Demand	881	1,337	1,787	2,292	2,797	3,401	4,057	Livingston, Allens Creek
		Reduction	0.00%	0.00%	20.90%	17.70%	18.30%	18.30%	18.30%	
		DOR Demand	881	1,337	1,414	1,887	2,286	2,780	3,316	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

Region H
Table E-1
Projected Water Demands Under Drought Conditions
All Values are listed in acre-ft per year

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
COUNTY-OTHER	80757036	Demand	481	463	443	424	406	393	387	Livingston
		Reduction	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	481	366	351	335	321	311	306	
COUNTY-OTHER	80757079	Demand	6,464	10,479	19,779	32,012	43,856	61,724	80,096	Livingston, Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	17.70%	17.70%	
		DOR Demand	6,464	10,479	19,779	27,348	37,466	50,809	65,932	
COUNTY-OTHER	80757084	Demand	1,272	1,098	948	851	795	764	750	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,006	869	750	673	629	604	593	
COUNTY-OTHER	80757101	Demand	13,367	11,193	8,612	7,713	11,809	16,314	20,733	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	10,576	8,856	6,814	6,103	9,343	12,908	16,404	
COUNTY-OTHER	80757170	Demand	14,307	21,619	26,954	38,344	51,726	70,827	93,011	Livingston
		Reduction	0.00%	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	14,307	21,619	26,954	30,338	40,926	56,038	73,590	
COUNTY-OTHER	80757204	Demand	1,264	1,428	1,603	1,731	1,795	1,833	1,858	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,000	1,130	1,268	1,370	1,420	1,450	1,470	
COUNTY-OTHER	80757228	Demand	484	526	558	561	547	522	502	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	383	416	441	444	433	413	397	
COUNTY-OTHER	80757236	Demand	8,339	9,466	10,373	10,793	10,637	10,639	10,639	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	6,598	7,489	8,207	8,539	8,416	8,418	8,418	
DEER PARK	80154000	Demand	4,312	4,364	4,370	4,401	4,424	4,514	4,641	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	3,412	3,453	3,458	3,482	3,500	3,571	3,672	
EL DORADO UD	84101000	Demand	427	465	507	544	584	627	675	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	427	465	401	430	462	496	534	
EL LAGO	80695000	Demand	548	534	524	513	503	496	496	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	434	423	415	406	398	392	392	
FALLBROOK UD	84109000	Demand	673	797	914	1,020	1,142	1,259	1,389	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	673	797	723	807	904	996	1,099	
FORT BEND COUNTY MUD #23	84121000	Demand	338	675	1,018	1,444	1,883	2,459	3,117	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	338	675	1,018	1,234	1,609	2,101	2,663	
FORT BEND COUNTY MUD #25	84122000	Demand	976	1,587	2,224	3,009	3,803	4,877	6,104	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	976	1,587	2,224	2,571	3,249	4,166	5,215	
FORT BEND COUNTY MUD #41	84125000	Demand	445	764	1,101	1,507	1,917	2,474	3,109	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	445	764	1,101	1,287	1,638	2,114	2,656	
FORT BEND COUNTY MUD #81	84129000	Demand	524	773	1,033	1,349	1,675	2,108	2,602	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	524	773	1,033	1,152	1,431	1,801	2,223	
FOUNTAINVIEW SUBDIVISION	84132000	Demand	290	341	389	438	483	532	585	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	290	341	308	347	382	421	463	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

Region H
Table E-1
Projected Water Demands Under Drought Conditions
All Values are listed in acre-ft per year

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
FRIENDSWOOD	80219000	Demand	3,968	4,276	4,537	4,631	4,590	4,610	4,651	Sources Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	3,139	3,383	3,590	3,664	3,632	3,647	3,680	
GALENA PARK	80226000	Demand	1,222	1,231	1,234	1,245	1,252	1,285	1,332	Livingston, Houston
		Reduction	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	20.30%	
		DOR Demand	975	982	984	993	998	1,024	1,061	
GRAND LAKES MUD #4	84142000	Demand	441	887	1,345	1,915	2,489	3,255	4,129	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	441	887	1,345	1,636	2,126	2,781	3,527	
GREEN TRAILS MUD	84143000	Demand	791	917	1,036	1,158	1,276	1,396	1,520	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	791	917	820	916	1,010	1,105	1,203	
GROVETON	80255000	Demand	109	119	126	127	123	118	113	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	86	94	100	100	97	93	89	
HARRIS COUNTY FWSD #51	84150000	Demand	2,345	2,536	2,473	2,451	2,409	2,409	2,409	Conroe
		Reduction	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	
		DOR Demand	1,762	1,906	1,858	1,842	1,810	1,810	1,810	
HARRIS COUNTY FWSD #6	84151000	Demand	292	346	396	441	494	544	601	Livingston, Conroe
		Reduction	24.90%	24.90%	22.50%	22.50%	22.00%	22.00%	22.00%	
		DOR Demand	219	260	307	342	385	424	469	
HARRIS COUNTY MUD #11	84153000	Demand	364	417	470	523	574	627	686	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	364	417	372	414	454	496	543	
HARRIS COUNTY MUD #119 INWOOD NORTH	84154000	Demand	750	878	919	899	880	870	870	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	750	878	727	711	696	688	688	
HARRIS COUNTY MUD #132	84157000	Demand	1,334	1,755	2,176	2,579	2,986	3,385	3,801	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,334	1,755	1,722	2,041	2,363	2,678	3,007	
HARRIS COUNTY MUD #150	84158000	Demand	1,123	1,248	1,370	1,482	1,599	1,726	1,867	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,123	1,248	1,084	1,173	1,265	1,366	1,477	
HARRIS COUNTY MUD #151	84159000	Demand	882	1,275	1,267	1,259	1,250	1,250	1,250	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	882	1,275	1,002	996	989	989	989	
HARRIS COUNTY MUD #152	84160000	Demand	560	787	1,014	1,228	1,444	1,670	1,895	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	560	787	802	972	1,142	1,321	1,499	
HARRIS COUNTY MUD #153	84161000	Demand	769	1,227	1,669	2,106	2,533	2,971	3,406	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	769	1,227	1,321	1,666	2,004	2,351	2,695	
HARRIS COUNTY MUD #154	84162000	Demand	525	676	830	974	1,122	1,265	1,421	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	525	676	657	771	888	1,001	1,124	
HARRIS COUNTY MUD #158	84165000	Demand	369	486	597	589	574	574	574	Livingston, Houston
		Reduction	0.00%	0.00%	20.90%	18.50%	18.50%	18.50%	18.50%	
		DOR Demand	369	486	472	480	468	468	468	
HARRIS COUNTY MUD #180	84170000	Demand	483	616	741	864	990	1,113	1,245	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	483	616	586	684	783	881	985	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

Region H
Table E-1
Projected Water Demands Under Drought Conditions
All Values are listed in acre-ft per year

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
HARRIS COUNTY MUD #189	84174000	Demand	634	804	970	1,133	1,299	1,462	1,636	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	634	804	767	896	1,028	1,157	1,294	
HARRIS COUNTY MUD #200	84176000	Demand	1,119	1,956	2,774	3,562	4,369	5,170	5,969	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,119	1,956	2,195	2,818	3,457	4,091	4,723	
HARRIS COUNTY MUD #261	84179000	Demand	876	870	867	867	865	865	865	Livingston, Houston
		Reduction	0.00%	8.90%	17.50%	17.50%	17.50%	17.50%	17.50%	
		DOR Demand	876	792	715	715	713	713	713	
HARRIS COUNTY MUD #33	84180000	Demand	881	1,001	1,109	1,225	1,336	1,453	1,578	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	881	1,001	877	969	1,057	1,150	1,249	
HARRIS COUNTY MUD #345	84182000	Demand	1,056	1,415	1,403	1,403	1,397	1,397	1,397	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,056	1,415	1,110	1,110	1,105	1,105	1,105	
HARRIS COUNTY MUD #46	84183000	Demand	566	836	822	808	801	801	801	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	566	836	650	639	634	634	634	
HARRIS COUNTY MUD #5	84184000	Demand	673	655	642	628	614	605	605	Livingston, Houston
		Reduction	0.00%	8.90%	17.30%	17.30%	17.30%	17.30%	17.30%	
		DOR Demand	673	597	531	519	508	500	500	
HARRIS COUNTY MUD #50	84185000	Demand	580	620	655	696	731	773	820	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	580	620	518	551	578	612	649	
HARRIS COUNTY MUD #53	84186000	Demand	1,491	1,933	2,384	2,806	3,238	3,658	4,111	Livingston, Conroe
		Reduction	24.90%	24.90%	22.50%	22.50%	22.00%	22.00%	22.00%	
		DOR Demand	1,120	1,452	1,848	2,175	2,526	2,854	3,207	
HARRIS COUNTY MUD #55	84187000	Demand	1,553	1,502	1,463	1,424	1,385	1,359	1,359	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,229	1,188	1,158	1,127	1,096	1,075	1,075	
HARRIS COUNTY MUD #8	84189000	Demand	637	697	756	809	866	929	1,001	Livingston, Houston
		Reduction	8.90%	8.90%	16.00%	16.00%	17.50%	17.50%	17.50%	
		DOR Demand	580	635	635	680	714	766	825	
HARRIS COUNTY UD #14	84190000	Demand	530	582	635	686	737	790	845	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	530	582	502	543	583	625	669	
HARRIS COUNTY UD #15	84191000	Demand	371	427	484	541	596	653	716	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	371	427	383	428	472	517	566	
HARRIS COUNTY WCID #1	84193000	Demand	968	1,115	1,264	1,413	1,554	1,704	1,870	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	766	882	1,000	1,118	1,230	1,348	1,480	
HARRIS COUNTY WCID #133	84195000	Demand	756	754	750	747	737	743	743	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	756	754	593	591	583	588	588	
HARRIS COUNTY WCID #21	84196000	Demand	1,373	1,417	1,466	1,509	1,547	1,609	1,684	Livingston, Conroe
		Reduction	24.90%	24.90%	23.00%	23.00%	22.30%	22.30%	22.30%	
		DOR Demand	1,032	1,065	1,130	1,163	1,202	1,250	1,308	
HARRIS COUNTY WCID #36	84197000	Demand	1,240	1,346	1,452	1,547	1,650	1,763	1,891	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,240	1,346	1,149	1,224	1,305	1,395	1,496	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

Region H
Table E-1
Projected Water Demands Under Drought Conditions
All Values are listed in acre-ft per year

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
HARRIS COUNTY WCID #36	84197001	Demand	0	0	0	0	0	0	0	Livingston, Conroe
		Reduction	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	
		DOR Demand	0	0	0	0	0	0	0	
HARRIS COUNTY WCID #50	84198000	Demand	547	605	663	715	770	830	897	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	547	605	525	566	609	657	710	
HARRIS COUNTY WCID #76	84199000	Demand	304	296	290	284	278	274	274	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	304	296	229	225	220	217	217	
HARRIS COUNTY WCID #84	84200000	Demand	599	602	604	606	604	611	621	Conroe
		Reduction	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	24.90%	
		DOR Demand	450	452	454	455	454	459	467	
HEDWIG VILLAGE	80269000	Demand	839	831	824	816	808	803	803	Livingston, Houston
		Reduction	15.50%	15.30%	15.20%	15.00%	14.90%	14.70%	14.60%	
		DOR Demand	709	704	699	693	688	685	686	
HILSHIRE VILLAGE	81025000	Demand	182	191	188	185	183	182	182	Livingston, Houston
		Reduction	0.00%	0.00%	17.90%	17.90%	17.90%	17.90%	17.90%	
		DOR Demand	182	191	154	152	150	149	149	
HOUSTON	80285000	Demand	347,947	389,082	429,218	467,036	506,047	547,787	593,096	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	275,296	307,842	339,597	369,519	400,384	433,409	469,258	
HUMBLE	80289000	Demand	3,233	3,664	4,062	4,456	4,857	5,274	5,715	Livingston, Houston
		Reduction	0.00%	8.90%	16.40%	16.40%	17.60%	17.60%	17.60%	
		DOR Demand	3,233	3,337	3,396	3,725	4,005	4,348	4,712	
HUNTERS CREEK VILLAGE	80290000	Demand	1,627	1,747	1,866	1,981	2,091	2,212	2,340	Livingston, Houston
		Reduction	14.20%	14.30%	16.30%	16.30%	17.10%	17.10%	17.10%	
		DOR Demand	1,397	1,498	1,563	1,658	1,734	1,834	1,939	
HUNTSVILLE	80292000	Demand	5,108	5,621	6,047	6,163	5,996	5,959	5,959	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	4,041	4,447	4,784	4,876	4,744	4,715	4,715	
IRRIGATION	81004036	Demand	117,777	117,777	117,777	117,777	117,777	117,777	117,777	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	117,777	117,777	117,777	117,777	117,777	117,777	117,777	
IRRIGATION	81004146	Demand	82,901	82,901	82,901	82,901	82,901	82,901	82,901	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	82,901	82,901	82,901	82,901	82,901	82,901	82,901	
IRRIGATION	81004170	Demand	66	66	66	66	66	66	66	Livingston, Houston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	66	66	66	66	66	66	66	
IRRIGATION	81004204	Demand	667	667	667	667	667	667	667	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	667	667	667	667	667	667	667	
IRRIGATION	81004228	Demand	467	467	467	467	467	467	467	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	467	467	467	467	467	467	467	
IRRIGATION	81004236	Demand	11	11	11	11	11	11	11	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	11	11	11	11	11	11	11	
JACINTO CITY	80301000	Demand	1,235	1,301	1,346	1,410	1,455	1,526	1,612	Livingston, Houston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.40%	20.40%	20.40%	
		DOR Demand	977	1,029	1,065	1,116	1,158	1,214	1,283	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
JERSEY VILLAGE	80709000	Demand	1,279	1,586	1,880	2,170	2,464	2,753	3,056	Livingston, Houston
		Reduction	0.00%	0.00%	17.60%	17.60%	17.60%	17.60%	17.60%	
		DOR Demand	1,279	1,586	1,550	1,789	2,032	2,270	2,520	
KATY	80312000	Demand	2,242	2,819	3,364	3,926	4,497	5,070	5,678	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	2,242	2,819	2,662	3,106	3,558	4,011	4,492	
KINGSBRIDGE MUD	84222000	Demand	926	1,229	1,550	1,926	2,302	2,818	3,400	Livingston, Allens Creek
		Reduction	0.00%	0.00%	20.90%	15.50%	15.70%	15.70%	15.70%	
		DOR Demand	926	1,229	1,226	1,628	1,940	2,374	2,865	
LA PORTE	80346000	Demand	4,928	5,323	5,673	6,078	6,412	6,830	7,298	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	3,899	4,212	4,488	4,809	5,073	5,404	5,774	
LIVINGSTON	80362000	Demand	1,741	1,778	1,814	1,831	1,844	1,872	1,905	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,377	1,407	1,435	1,449	1,459	1,481	1,507	
LONGHORN TOWN UD	84235000	Demand	327	596	857	1,112	1,368	1,622	1,875	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	327	596	678	880	1,082	1,283	1,484	
MANUFACTURING	81001020	Demand	221,930	260,239	286,554	309,841	333,348	354,093	379,241	Allens Creek
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	221,930	260,239	286,554	309,841	333,348	354,093	379,241	
MANUFACTURING	81001036	Demand	9,752	11,802	12,959	13,987	15,011	15,932	17,122	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	9,752	11,802	12,959	13,987	15,011	15,932	17,122	
MANUFACTURING	81001084	Demand	35,381	41,005	44,330	47,046	49,692	51,967	55,491	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	35,381	41,005	44,330	47,046	49,692	51,967	55,491	
MANUFACTURING	81001101	Demand	349,420	395,997	424,761	449,218	470,881	487,094	478,957	Livingston, Houston, Conroe
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	349,420	395,997	424,761	449,218	470,881	487,094	478,957	
MASON CREEK UD	84247000	Demand	2,273	2,352	2,321	2,291	2,271	2,261	2,261	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	2,273	2,352	1,836	1,813	1,797	1,789	1,789	
MINING	81003036	Demand	31,027	37,422	40,532	42,427	44,286	46,130	47,742	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	31,027	37,422	40,532	42,427	44,286	46,130	47,742	
MINING	81003101	Demand	1,011	1,282	1,434	1,529	1,624	1,720	1,805	Livingston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	1,011	1,282	1,434	1,529	1,624	1,720	1,805	
MISSOURI CITY	80409000	Demand	10,239	15,862	19,589	23,349	27,226	30,188	36,466	Livingston, Allens Creek
		Reduction	0.00%	0.00%	20.90%	15.00%	15.80%	19.20%	19.20%	
		DOR Demand	10,239	15,862	15,499	19,849	22,915	24,384	29,455	
MONT BELVIEU	80413000	Demand	718	983	1,278	1,549	1,785	2,030	2,281	Livingston
		Reduction	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	718	778	1,011	1,226	1,412	1,606	1,805	
NASSAU BAY	80424000	Demand	1,042	1,028	1,014	1,000	986	976	976	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	824	813	802	791	780	772	772	
NHCRWA	88000000	Demand	81,393	101,015	120,164	138,646	157,390	175,778	195,040	Livingston, Houston, Conroe
		Reduction	0.00%	24.90%	18.70%	18.70%	18.70%	18.70%	18.70%	
		DOR Demand	81,393	75,903	97,680	112,703	127,940	142,887	158,545	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
NORTH BELT UD	84275000	Demand	317	461	600	731	863	1,002	1,140	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	317	461	475	578	683	793	902	
NORTH GREEN MUD	84279000	Demand	319	349	379	405	434	466	503	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	319	349	300	320	343	369	398	
NORTH MISSION GLEN MUD	84283000	Demand	520	867	1,239	1,688	2,140	2,755	3,458	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	520	867	1,239	1,442	1,828	2,354	2,954	
NORTHWEST HARRIS COUNTY MUD #23	84286000	Demand	442	587	728	873	1,005	1,152	1,298	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	442	587	576	691	795	911	1,027	
NORTHWEST PARK MUD	84287000	Demand	1,216	1,331	1,443	1,545	1,653	1,773	1,909	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,216	1,331	1,142	1,222	1,308	1,403	1,510	
OLD RIVER-WINFREE	80727000	Demand	186	194	206	216	223	233	247	Livingston
		Reduction	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	186	153	163	171	176	184	195	
ONALASKA WSC	84293000	Demand	239	240	244	247	242	246	255	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	189	190	193	195	191	195	202	
PASADENA	80456000	Demand	18,567	20,465	22,321	24,009	25,790	27,740	29,927	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	14,690	16,192	17,660	18,996	20,405	21,948	23,678	
PEARLAND	80457000	Demand	5,650	9,544	11,873	13,910	15,839	17,994	20,240	Livingston, Houston, Allens Cree
		Reduction	20.90%	20.90%	20.90%	14.40%	14.50%	14.50%	14.50%	
		DOR Demand	4,470	7,551	9,394	11,913	13,549	15,392	17,314	
PINE TRAILS UTILITY	84302000	Demand	871	939	1,008	1,070	1,137	1,210	1,292	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	689	743	798	847	900	957	1,022	
PINEY POINT VILLAGE	80468000	Demand	1,230	1,275	1,317	1,360	1,402	1,451	1,506	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	973	1,009	1,042	1,076	1,109	1,148	1,192	
RICHMOND	80500000	Demand	1,899	2,032	2,176	2,353	2,527	2,799	3,131	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	1,899	2,032	2,176	2,010	2,159	2,391	2,675	
RIVERSIDE WSC	84323000	Demand	377	449	504	548	558	562	568	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	298	355	399	434	441	445	449	
ROLLING FORK PUD	84411000	Demand	682	706	729	753	777	806	839	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	682	706	577	596	615	638	664	
ROSENBERG	80518000	Demand	3,420	3,872	4,306	4,866	5,457	6,286	7,289	Allens Creek
		Reduction	0.00%	0.00%	0.00%	14.60%	14.60%	14.60%	14.60%	
		DOR Demand	3,420	3,872	4,306	4,157	4,662	5,370	6,227	
SAN JACINTO WSC	84328000	Demand	337	406	474	528	561	577	587	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	267	321	375	418	444	457	464	
SEABROOK	80545000	Demand	1,967	2,421	2,867	3,288	3,731	4,166	4,620	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,556	1,915	2,268	2,601	2,952	3,296	3,655	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
SHOREACRES	80558000	Demand	192	204	217	229	239	237	237	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	152	161	172	181	189	188	188	
SOUTH HOUSTON	80569000	Demand	2,164	2,288	2,393	2,528	2,631	2,775	2,942	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,712	1,810	1,893	2,000	2,082	2,196	2,328	
SOUTHSIDE PLACE	80572000	Demand	379	406	433	458	482	510	540	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	300	321	343	362	381	404	427	
SOUTHWEST UTILITIES	84343000	Demand	890	1,036	1,158	1,320	1,485	1,688	1,925	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	890	1,036	916	1,044	1,175	1,336	1,523	
SPRING VALLEY	80575000	Demand	858	888	915	944	972	1,008	1,049	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	858	888	724	747	769	798	830	
STEAM ELECTRIC POWER	81002101	Demand	7,606	7,728	23,962	28,015	32,955	38,977	46,317	Livingston, Conroe
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	7,606	7,728	23,962	28,015	32,955	38,977	46,317	
STEAM ELECTRIC POWER	81002170	Demand	2,507	5,046	8,537	9,981	11,741	13,886	16,502	Houston
		Reduction	-	-	-	-	-	-	-	
		DOR Demand	2,507	5,046	8,537	9,981	11,741	13,886	16,502	
SUNBELT FWSD	84350000	Demand	3,741	4,489	5,227	5,922	6,663	7,389	8,154	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	2,960	3,552	4,136	4,685	5,272	5,846	6,451	
TAYLOR LAKE VILLAGE	80751000	Demand	629	664	650	637	623	619	619	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	498	525	514	504	493	490	490	
TOMBALL	80608000	Demand	2,016	2,621	3,301	3,842	4,834	5,562	6,630	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	2,016	2,621	2,612	3,040	3,825	4,401	5,246	
TRAIL OF THE LAKES MUD	84355000	Demand	549	1,413	1,376	1,364	1,339	1,339	1,339	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	549	1,413	1,089	1,079	1,059	1,059	1,059	
TRINITY	80610000	Demand	165	170	172	165	152	142	137	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	131	135	136	131	120	112	108	
TRINITY RURAL WSC	84363000	Demand	290	307	324	324	311	297	287	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	229	243	256	256	246	235	227	
WALLER	80629000	Demand	433	535	642	762	893	1,042	1,213	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	433	535	508	603	707	824	960	
WEBSTER	80635000	Demand	1,719	2,417	3,097	3,772	4,432	5,110	5,786	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	1,360	1,912	2,450	2,984	3,507	4,043	4,578	
WEST HARRIS COUNTY MUD #6	84387000	Demand	301	565	561	561	549	541	541	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	301	565	444	444	434	428	428	
WEST UNIVERSITY PL.	80643000	Demand	2,929	3,101	3,275	3,438	3,591	3,780	3,989	Livingston
		Reduction	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	2,317	2,454	2,591	2,720	2,841	2,991	3,156	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

Region H
Table E-1
Projected Water Demands Under Drought Conditions
All Values are listed in acre-ft per year

wug_name	wug_id	Demand	WD2000	WD2010	WD2020	WD2030	WD2040	WD2050	WD2060	Reservoir Sources
WHCRWA	88002000	Demand	43,344	49,309	60,462	72,967	81,304	90,116	99,900	Livingston, Houston, Conroe
		Reduction	0.00%	24.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	43,344	37,051	47,818	57,709	64,303	71,272	79,010	
WILLOW RUN SUBDIVISION	84398000	Demand	681	665	652	640	628	620	620	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	681	665	516	506	497	491	491	
WINDFERN FOREST UD	84401000	Demand	573	804	1,033	1,014	1,004	1,004	1,004	Livingston
		Reduction	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	573	636	817	802	794	794	794	
WOODCREEK MUD	84404000	Demand	426	622	815	999	1,184	1,374	1,564	Livingston
		Reduction	0.00%	0.00%	20.90%	20.90%	20.90%	20.90%	20.90%	
		DOR Demand	426	622	645	790	937	1,087	1,237	

Note: Drought of Record Demands (DOR DEMANDS)
are reduced by Drought Management Plans

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APPENDIX F

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APPENDIX G

TWDB Comments

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ATTACHMENT 1

TWDB Contract No. 0704830693

Region H, Region-Specific Studies 1 - 3:

TWDB Comments on Draft Final Region-Specific Study Reports:

1. **Environmental Flows Investigations for Region H**
2. **Impact of Drought Management Strategies on Surface Water Reservoirs in Region H**
3. **Interruptible Water Supplies**

Region-Specific Study Number 1: Environmental Flows Investigations for Region H

1. Page ES-3, Max H definition: Please replace "annual inflows" with "sequence of monthly inflows" to more correctly define Max H.

2. Page ES-3, Min Q definition: Please replace "minimum annual inflow" with "sequence of monthly inflows that minimizes annual volume needed" to more correctly define Min Q

3. Page ES-3, Min Q-Sal definition: Please replace entire definition with "sequence of monthly inflows that maintains B&E salinity constraint". The Min Q-Sal condition has no harvest or production goal, but merely meets the constraint.

4. Page ES-4, 1st paragraph: Please provide reference for GBFIG-proposed frequencies. Also, please provide how the GBFIG document defines "frequency of attainment".

5. Page ES-4, last paragraph: Please more clearly explain how seasonal Frequency of Target Attainment (FTA) was developed and presented in Figure ES-3, noting if the monthly flows were summed and if the same was done for seasonal target flows. Also, please note that based on Figure ES-1, March might better belong in the winter season than in the spring season.

6. Page ES-8, 2nd paragraph, 2nd sentence: Please clarify that the frequency goals are those as defined by GBFIG and evaluated in the report.

7. Page ES-12, 1st sentence: TWDB conducted a Streamflow Assessment for the 2007 State Water Plan. Please correct the reference in this sentence.

8. Pages ES-14 and 4-3, Tables ES-7 and 4-2: Footnote 1 states that the flow was estimated to be below the Lyons flow. The tables show Lyons flow to be 1,217 cfs, and the observed flow to be <10,000 cfs. Please clarify the observed flow value.

9. Page ES-17, Instream Flows Conclusion 3: This conclusion states that "Despite this flow condition, there were no indications of impaired stream health ...". Please explain if there was any indication that the observed low flows had occurred for significant enough time for there to be an ecological response. Also, please explain if this flow condition is a significant factor in using the TCEQ Surface Water Quality Monitoring procedures.

10. Page 3-8, 2nd paragraph, 1st sentence: The sentence states "It was assumed that B&E inflow targets are achieved by any flow that equals or exceeds the target flow; thus, flow cannot be too high for the target, but can be too low." Since this statement applies to the Max H target, it appears to be inaccurate. Fisheries harvest has been shown to decrease with an excessive volume of fresh water (i.e. flow can be too high for the target). Please clarify or revise the statement.

11. Page 5-3, Figure 5-1: In the figure title, please consider clarifying by changing "Trinity Basin B&E Discharge" to "Trinity Basin B&E Median Monthly Discharge".

Region-Specific Study Number 2: Impact of Drought Management Strategies on Surface Water Reservoirs in Region H

1. Page 2-2, last sentence: Refers to "Figure 1". Please correct all figure references (e.g. to 'Figure 2-1') throughout report.

2. Page 2-3, 1st line and Figure 2-1: Please elaborate on the reasonableness and basis for the assumption that "non-seasonal (e.g., indoor) water uses are more or less the same in each community," considering the variations in city sizes and socioeconomic conditions. In addition, please note this assumption ignores the influence of commercial water use, which is also a part of per capita water use for some entities.

3. Sections 4 and 5: Please consider clarifying in Section 5 the impacts to "storage capacity" or "full permitted capacity" in Section 4.

4. Page 5-2, Table 5 (and similar tables thereafter): Please consider providing an explanation of how a decimal point of months is obtained with WAM's monthly time step of simulation.

5. Section 7: Please clarify in the text that the graphs in this section are based upon firm yield of these reservoirs.

6. Page 7-4, Table 22: In Table 22, the meaning of 'Impact' is unclear from the limited table content. Please clarify the meaning of the 'Impact' field.

7. Page 8-1, 6th paragraph; and page 8-2, bullet #6: The basis for the conclusion that the "stretching of water supplies due to drought contingency measures are relatively insignificant in terms of annual increased supply and certainly non significant in the context of long-term water planning." does not appear to be supported by the analysis (e.g. 150,000 acre-feet of water at Lake Livingston per figure 7-1) especially considering that long-term regional water planning is based on addressing limited term, drought-of-record conditions. Please substantiate or modify the conclusion.

8. Appendix E: Please indicate what units the values represent in this appendix.

Region-Specific Study Number 3: Interruptible Water Supplies

1. Page 1-1, 2nd paragraph, 1st sentence: The planning guidelines of the TWDB allow for the use of "safe yield" for planning purposes if approved by the Executive Administrator. Please clarify this statement in the final report.

2. Page 3-1, 2nd paragraph, lines 11-12: Please consider clarifying the statement that the monthly test "does not consider the magnitude of monthly diversions".

3. Page 3-2, 3rd paragraph, last sentence: Please consider elaborating on why over-appropriation is indicated if the interruptible supply portion exceeds firm yield.

4. Page 3-3, 5th sentence: The word "form" should be "from". Please correct.

5. Page 3-3, Table 8: Please verify the permitted amount for the two water rights presented in the table.

6. Page 3-12. Figure 3-1 is also identified as Figure 5. Please clarify the figure numbering.

7. Page 3-13, 1st paragraph, 2nd line: Reference is made to Figure 2.1 and should be made to Figure 3-1. Please correct.

8. Page 3-14. Figure 3-2 is also identified as Figure 6. Please clarify the figure numbering.

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KBR

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Memorandum

Date	July 2009
To	J. Kevin Ward Executive Administrator Texas Water Development Board 1700 North Congress Avenue Austin, TX 78701
From	Karim El Kheiashy, P.E.
Subject	Response to TWDB Comments on Region H 1st Biennium Drought Management Study Draft Report for 2011 Regional Water Planning Round

The following text addresses TWDB comments on the Region H Drought Management Study and is intended to supplement edits to the report text. TWDB comments are in italics, with KBR responses in regular text.

1. *Page 2-2, last sentence: Refers to "Figure 1." Please correct all figure references (e.g. to 'Figure 2-1') through report.*

   This change has been made in Section 2.3

2. *Page 2-3, 1st line and Figure 2-1: Please elaborate on the reasonableness and basis for the assumption that "non-seasonal (e.g. indoor) water uses are more or less the same in each community," considering the variation in city sizes and socioeconomic conditions. In additions, please note this assumption ignores the influence of commercial water use, which is also a part of per capita water use for some entities.*

   The following text has been added to Section 2.3. Additional text is shown in *underlined italics.*

   "As demonstrated in Figure 2-1, per capita municipal water demands for communities in Region H vary widely and, if one makes *the rough assumption* that non-seasonal (e.g., indoor) water uses are more or less the same in each community, then the differences in per capita water demand can be attributed largely to seasonal water uses. *This assumption ignores city size, socioeconomic conditions, and the influence of commercial and institutional water use that is part of the per capita demand of some entities.*"

3. *Sections 4 and 5: Please consider clarifying in Section 5 the impacts to "storage capacity" or "full permitted capacity" in Section 4.*

   The impact of drought contingency modeling on reservoirs in Region H was evaluated by quantifying the increased storage volume in the reservoir during the drought of record and does not affect the full permitted capacity of the reservoir.

KBR

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The following text has been added to Section 5: "Modeling drought management measures resulted in an increase in the minimum volume of water stored in the reservoirs during the drought of record. This increase in storage volume was compared to the results presented in Section 4 and is presented in this section as the number of months of remaining supply. A

4. *Page 5-2, Table 5 (and similar tables thereafter): Please consider providing an explanation of how a decimal point of months is obtained with WAM's monthly time step of simulation.*

   The number of months was determined by dividing the remaining storage volume by the monthly diversion target. The following text has been added to Sections 5.1, 5.2, 5.3 and 5.4.

   "The minimum storage volume identified from the WAM output was divided by the projected demands to estimate the months of remaining supply."

5. *Section 7: Please clarify in the text that the graphs in this section are based upon firm yield of the reservoirs.*

   The following text has been added to Section 7 for clarification:

   "Lake Livingston, Lake Houston and Allens Creek were modeled assuming the firm yield of the reservoirs. Lake Conroe was modeled assuming the full permitted capacity of 100,000 afy."

6. *Page 7-4, Table 22: In Table 22, the meaning of 'Impact' is unclear from the limited table content. Please clarify the meaning of the 'Impact' field.*

   The following text has been added to Section 7 for clarification:

   "Table 22 lists the water management strategies recommended in the 2006 Region H water plan and identifies the possible impacts on the timing and magnitude of the selected strategies."

   In addition the word "Impact" in Table 22 has been changed to "Impact to implementation".

7. *Page 8-1, 6th paragraph; and page 8-2, bullet #6: The basis for the conclusion that the "stretching of water supplies due to drought contingency measures are relatively insignificant in terms of annual increase supply and certainly non significant in the context of long-term water planning." Does not appear to be supported by the analysis (e.g. 150,000 acre-feet of water at Lake Livingston per figure 7-1) especially considering that long-term regional water planning is based on addressing limited term drought-of-record conditions. Please substantiate or modify the conclusion.*

   The following text has been added to the discussion in Section 8 to substantiate to conclusion:

   "While implementation of drought contingency measures can save substantial volumes of water during drought of record conditions, little to no water is made available during normal hydrologic conditions. As a result, the water saved is only available on an interruptible basis and does not represent an increase in annual supply. The allocation of an interruptible supply as an annual supply to meet demands that are present in both normal hydrologic and drought conditions would be inconsistent with the purpose of long-term water planning. Water saved through implementation of drought contingency measures

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may be used on an interruptible basis as part of a conjunctive use strategy. Further more, the 150,000 acre-ft that is made available in Lake Livingston is not available in every year during the drought of record, much less every month."

The following text has been added to bullet #6 in Section 8 to substantiate the conclusion:

"Long term water planning assumes that only the firm yield from reservoirs is available for allocation. Water saved by implementing drought contingency measures would only be available on an interruptible basis during drought conditions. As a result, the saved water could only be allocated to meet demands that are present on an interruptible basis; that is, the increase in demands above normal hydrologic conditions in response to drought conditions. Under this scenario, implementation of drought contingency measures could be used to reduce dry year demands down to average year demand levels. Traditional supply sources and long-term water management strategies would still be required to supply average year demands."

8. *Appendix E. Please indicate what units the values represent in this appendix.*

The unit of measure for the table provided in Appendix E is acre-ft. The change has been made to Appendix E.