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BASINS 4.0 Climate Assessment Tool (CAT): Supporting Documentation and Users Manual

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PREFACE

The U.S. Environmental Protection Agency's Global Change Research Program (GCRP) is an assessment-oriented program within the Office of Research and Development that focuses on assessing how potential changes in climate and other global environmental stressors may impact water quality, air quality, aquatic ecosystems, and human health in the United States. The Program's focus on water quality is consistent with the *Research Strategy* of the U.S. Climate Change Research Program—the federal umbrella organization for climate change science in the U.S. government—and is responsive to U.S. EPA's mission and responsibilities as defined by the Clean Water Act and the Safe Drinking Water Act. A central goal of the EPA GCRP is to provide EPA program offices, Regions, and other stakeholders with tools and information for assessing and responding to any potential future impacts of climate change.

In 2006 the EPA Global Change Research Program (GCRP) supported the development of a Climate Assessment Tool (CAT) for the EPA Office of Water's Version 4 release of the BASINS water quality modeling system. This report provides supporting documentation and user support materials for the BASINS CAT tool.

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Executive Summary

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). Projecting forward, continued warming temperatures and changes in the amount, form, and intensity of precipitation are expected, albeit with large and poorly understood regional variations.

The impacts of climate change on water and watershed systems will present, in many areas, significant additional risk associated with the provision of safe, reliable water supplies, compliance with water quality regulations, and the protection of aquatic ecosystems. Meeting this challenge will require tools and information that allow water managers to explicitly address the implications of climate change at the watershed scale in their decision making process.

The EPA Office of Research and Development, Global Change Research Program, in partnership with EPA Office of Water supported the development of a Climate Assessment Tool (CAT) for the Office of Water's BASINS 4 water quality modeling system. BASINS is a multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art modeling tools including the watershed models HSPF and SWAT into one package. BASINS CAT provides additional capabilities for assessing the influence of climate variability and change on water quantity and quality at the watershed scale. The basic philosophy behind BASINS CAT is to provide flexible capabilities for creating and running climate change scenarios within the BASINS system. It's important to note that BASINS does not provide actual data or other information about climate change. Rather, CAT simply provides the capability for users to create and run scenarios reflecting changes they determine to be of interest in their specific region or watershed. This capability is intended to support BASINS users interested in assessing a wide range of "what if" questions about how weather and climate could affect their systems. Combined with the existing capabilities of BASINS models for assessing the impacts of land use change and management practices, the climate assessment capabilities provided by the CAT allow BASINS users to assess the impacts of alternative futures including climate and land use change as well as implementation of adaptation strategies (e.g. BMPs) for increasing resilience to climate change.

The purpose of this report is to provide in a single document a variety of documentation and user support materials supporting the use of BASINS CAT. The report contains 6 chapters: Chapter 1 is a brief summary of the general philosophy behind development of BASINS CAT, Chapter 2 provides a "what and why" discussion of BASINS CAT capabilities, Chapter 3 illustrates application of the tool through a series hands-on of tutorials, Chapter 4 provides additional basic information about the development and application of the tool in the form of a user's manual, Chapter 5 briefly describes a case study application of BASINS CAT illustrating the use of the tool to assess the potential impacts of climate change on a mid-Atlantic watershed, and Chapter 6 is a listing of additional resources for learning more about climate change and the potential impacts of climate change on water resources. The material presented in this report will also be made available in a keyword searchable form through the online help function within the Office of Waters BASINS web site.

BASINS CAT is seamlessly integrated into the BASINS system through a series of graphical user interfaces. Specifically, application of BASINS CAT requires a pre-existing, calibrated HSPF application, a WDM file containing HSPF input meteorological time series, and an output file(s) to which HSPF results are output (WDM and/or Binary)

BASINS CAT essentially provides additional capabilities to BASINS users in 2 general areas; a flexible preprocessing capability for creating meteorological time series reflecting any user-determined change in temperature and precipitation for use as input to the HSPF model, and a post-processing capability for calculating management targets (endpoints) useful to water and watershed managers from model output.

BASINS CAT enables adjustments to historical records of only two meteorological data types, precipitation and air temperature. Users can adjust historical data using standard arithmetic operators applied monthly, seasonally or over any other increment of time. This flexibility allows adjustments to be made reflecting long term seasonal climate change, as well as short-term, year-to-year changes such as changes in the intensity of periodic drought. In addition, adjustments to a climate variable can also be applied uniformly to all “events”, or be selectively imposed only on those historical events that exceed (or fall below) a specified threshold. Future climate change is expected to result in an acceleration or ‘intensification’ of the hydrologic cycle, whereby a greater proportion of annual precipitation occurs as larger magnitude events. A general trend during the 20th century towards increasing precipitation intensity has already been shown throughout the U.S. The ability to selectively adjust only events within user-defined size classes allows climate change scenarios to be created reflecting these changes. Finally, CAT also provides a capability for users to create time series that contain more frequent precipitation events.

The post-processing capability provided by CAT allows users to calculate hydrologic or water quality endpoint metrics such as an x-year, y-duration high or low flow event, an annual water yields, or an annual pollutant load. This capability provides a unique opportunity for water and watershed managers to assess the impacts of climate change in terms of the metrics that are traditionally used for understanding impacts and making decisions within their specific professions or management domains. The user may select as endpoints any HSPF state variable or flux that is being modeled and output as a result of the model set up. If so desired, CAT enables users to further refine their analyses by considering only time periods of concern.

A series of step-by-step tutorials are provided illustrating application of the tool to creating scenarios reflecting a wide range of potential changes in climate. A users manual and case study assessment using BASINS CAT provide additional information about how BASINS CAT can be used to understand and manage the potential impacts of climate change on water and watershed systems.

1.0 Introduction

Watershed systems are influenced by climatic drivers including the amount, form, seasonality, and event characteristics of precipitation, as well as temperature, solar radiation, wind and other factors affecting hydrologic and biogeochemical processes (Gleick and Adams, 2000). The seasonal dynamics of snow accumulation and melt are particularly important in the northwest and mountainous regions. Changes in any of these attributes can influence the amount, timing and/or location of surface runoff, groundwater recharge, and the quality of water. Climate also interacts strongly with human use and demand for water, water treatment and other built infrastructure, and non-climatic watershed stressors such as non-point pollution loading and urban stormwater runoff. Ultimately, these changes may be reflected in key management targets, such as frequency flow events (e.g., the 100-year flood), maximum water temperatures, or nutrient loads.

Managing the risk associated with seasonal to annual climate variability has long been a principal focus of water and watershed management. Management plans are developed, and water infrastructure is designed and operated to be resilient to anticipated variability in climate. In most areas, however, instrumental records are limited to a relatively short period within the twentieth century, and estimates of future conditions are made assuming that climate is stationary. There is growing concern, however, that this assumption may no longer be valid, and that long term climatic trends may lead to unprecedented future conditions and events (IPPC, 2007).

There is now general consensus among climate scientists that human activities including the combustion of fossil fuels and landcover change have resulted in, and will likely continue to result in, long-term climatic change (IPCC, 2007). The 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level” (IPCC, 2007). The global average temperature has risen 1.4^{o}F in the last century. At the same time many regions have experienced changes in precipitation amount, and an increase in the frequency of heavy precipitation events (i.e. the proportion of annual precipitation occurring as heavy precipitation events; IPCC, 2007). Projecting forward, continued warming temperatures and changes in the amount, form, and intensity of precipitation are expected, albeit with large and poorly understood regional variations.

The impacts of climate change on water and watershed systems will present, in many areas, significant additional risk associated with the provision of safe, reliable water supplies, compliance with water quality regulations, and the protection of aquatic ecosystems. In addition, independent of the behavior of the climate, demographic and socioeconomic changes may increase the vulnerability of certain regions or sectors to current climatic variability. To reduce the likelihood of future impacts, water managers must be able to assess potential risks and opportunities, and where appropriate, implement practices and strategies to adapt to future climatic conditions. Meeting this challenge will require tools and information that allow water managers to explicitly address the implications of climate change at the watershed scale in their decision making process.

The EPA Office of Research and Development, Global Change Research Program, in partnership with EPA Office of Water supported the development of a Climate Assessment Tool (CAT) for the Office of Water's BASINS 4 water quality modeling system. BASINS is a multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art modeling tools including the watershed models HSPF and SWAT into one package (U.S. EPA, 2001; see http:// www.epa.gov/waterscience/basins/). BASINS CAT provides additional capabilities for assessing the influence of climate variability and change on water quantity and quality at the watershed scale. Combined with the existing capabilities of BASINS models for assessing the impacts of land use change and management practices, the climate assessment capabilities provided by the CAT allow BASINS users to assess the impacts of alternative futures including climate and land use change as well as implementation of adaptation strategies (e.g. BMPs) for increasing resilience to climate change. The CAT itself does not, however, provide an explicit capability for developing and running land use and BMP scenarios.

The purpose of this report is to compile in a single document a variety of documentation and user support materials useful to BASINS CAT users.

1.1 Development Philosophy

Recent advances in climate science have greatly improved our understanding of Earth's climate including the multiple, complex natural and anthropogenic processes governing long term climate change. Current climate models are extremely useful for understanding general system behavior, response to climate forcing, and for characterizing broad scale pattern and trends. Current climate models are less skilled, however, at predicting climate at the local and regional scales needed by water managers. It is thus not possible to know with certainty the future climatic conditions to which a given region or watershed will be exposed. Accurate predictions of future climate should not be considered a necessary precursor, however, to taking action (Sarewitz et al., 2000). An alternative approach is to consider the response of a watershed or water system to a range of plausible future climatic conditions, termed "climate scenarios" (IPCC-TGCIA, 2007). Using scenario analysis, water managers can assess their exposure to climate-related risks, and using this information effectively manage risk by implementing practices and strategies to make systems robust to a wide range of plausible future conditions and events (Sarewitz et al., 2000).

The climate scenarios used in scenario analysis can be developed in a variety of ways depending on the type(s) of information about climate change available and, equally as importantly, the goals and requirements of a specific assessment activity. Each scenario should be generally consistent with global projections of change, physically plausible, and applicable in the context of a particular assessment activity. Collectively, the set of scenarios considered should be representative of a broad range of future changes that a given region or watershed may experience. An excellent, comprehensive reference on the use of scenario data for assessing climate change impacts and adaptation is available from the IPCC (IPCC-TGICA, 2007; http://unfccc.int/resource/cd_roms/na1/v_and_a/Resoursce_materials/Climate/ScenarioData.pdf).

The IPCC-TGCIA describes three different types of scenarios based on different types of information about climate: synthetic scenarios, analogue scenarios, and scenarios based on outputs from climate models. Synthetic scenarios describe techniques where particular climatic attributes are changed by a realistic but arbitrary amount, often according to a qualitative interpretation of climate model simulations for a region. For example, adjustments of baseline temperatures by +1, 2, 3 and 4°C and baseline precipitation by ±5, 10, 15 and 20 percent could represent various magnitudes of future change (IPCC-TGIA, 2007). Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. These records can be obtained either from the past (temporal analogues) or from - another region at the present (spatial analogues). Model based scenarios are developed using output from modeling experiments with GCM (General Circulation Model) and RCM (Regional Climate Model) models that simulate the response of the global climate system to increasing greenhouse gas concentrations. A more detailed discussion of climate models and scenarios based on climate models is provided by the IPCC-TGICA.

The philosophy behind BASINS CAT is to provide flexible capabilities for creating and running climate change scenarios like those described by the IPCC-TGICA within the BASINS system. It’s important to note that BASINS does not provide actual data or other information about climate change for any particular region. Rather, CAT simply provides the capability for users to create and run scenarios reflecting changes they determine to be of interest in their specific region or watershed. This capability is intended to support BASINS users interested in assessing a wide range of “what if” questions about how weather and climate could affect their systems.

The general concept of a pre-processing capability allowing model users to create climate change scenarios for assessment is applicable to any modeling platform. BASINS was considered an ideal platform for such a tool, however, as it is well known, widely distributed, and provides access to several watershed models and other tools supporting watershed management. Moreover, water and watershed systems are also impacted by non-climatic stressors such as landcover change and pollutant discharges. In many areas these impacts may be greater than those due to changes in climate. It is thus important to understand climate change impacts in the context of specific watersheds and all stressors affecting the system. The BASINS system was developed to support assessments of watershed land use change, pollutant discharges, and management practices on water quality (U.S. EPA, 2007). As mentioned previously, BASINS models have an existing capability for assessing the impacts of land use change, and the climate assessment capabilities provided by the CAT allow BASINS users to assess the combined impacts of climate and land use change. The CAT does not, however, provide an explicit capability for developing and running land use change scenarios.

The actual, specific components of a climate scenario necessary for conducting an assessment are meteorological data reflecting the potential changes of concern at a spatial and temporal resolution suitable for running a hydrologic model or otherwise informing upon a decision. If GCM and/or RCM data of adequate resolution is available, climate model output can be used directly as the necessary meteorological data for use with a hydrologic or other model. Direct use of data from climate models restricts the number and type of scenarios able to be evaluated, however, and the coarse spatial resolution of climate models can limit applicability. An alternative approach is to couple available information about climate and climate change with a stochastic weather generator to produce meteorological data at the necessary temporal and spatial resolution for developing scenarios. Stochastic weather generators are a powerful tool useful for a variety of applications, but their utility is limited in studies of large watersheds where the spatial heterogeneity of climate must be represented. The problem results from the fact that each run with a weather generator is a randomly generated time series, thus the spatial correlation structure among adjacent or nearby locations represented by different runs is lost. A final approach for creating scenarios is by modifying representative windows of historical weather data from specific locations (e.g. NCDC weather stations) to reflect information about future climate change from any available source, or otherwise to reflect any potential change of concern. This last approach, modifying historical weather data, is the approach used by BASINS CAT. It is relatively simple to implement, able to represent a wide range of potential changes based on any available knowledge, whether quantitative or qualitative, about future climate change, and the spatial correlation structure among adjacent locations can be maintained in applications to large watersheds (by modifying existing weather records from all locations over the same base period the spatial correlation structure is preserved).

Change scenarios are created with CAT by selecting a period of historical data to be modified (e.g. from an NCDC weather station used as meteorological input to a watershed model), and performing a series of operations or “adjustments” on that baseline time series. CAT allows adjustments to temperature and precipitation time series. Creating scenarios by modifying historical data provides a simple but effective form of spatial and temporal downscaling, whereby projected climate change data at coarse spatial resolution (e.g. GCM grid cells) is interpolated to the location of individual weather stations, and projected change data at coarser temporal resolution (e.g. monthly or seasonal average changes) is applied to finer resolution data from the historical record (e.g. daily or hourly data at specific weather station).

As described previously, scenarios can be developed based on any available information about climate change and/or user goals for an analysis. For example, scenarios can be developed to reflect re-occurrence of an extreme historical condition or event, to specifically address a hypothesis about the sensitivity of a hydrologic or water quality endpoint to a particular type of climate change, or to reflect attributes of a projection based on a climate modeling experiment. In each case, creating a scenario using BASINS CAT requires that the user express the desired change as a series of adjustments to historical time series using the specific capabilities provided by CAT. BASINS CAT was developed with a range of capabilities for adjusting time series intended to provide the flexibility needed to represent a wide range of potential climate change. When developing scenarios to reflect specific changes such as a projection from a climate modeling experiment, the types of adjustment possible are limited by the available information (e.g. the type and temporal resolution of available information such as projected monthly versus seasonal average temperature changes). With respect to model based projection data, this often a function of the way data is summarized and distributed. Creating scenarios based on historical variability or some other type of historical observation is similarly limited by the type and resolution of observations (e.g. annual versus monthly low precipitation). Ultimately, however, the requirements for creating scenarios suitable for an assessment activity depend on the context and goals of the assessment.

In addition to supporting the creation of scenarios, CAT also manages the input and processing of scenarios using HSPF watershed model (BASINS CAT is currently available only with the HSPF model).

BASINS CAT also provides a post-processing capability to calculate a range of user selected hydrologic and water quality management targets or "endpoints" such as mean annual flow, a mean monthly flow, 100-year flood event, 10-year seven-day (7Q10) low flow event, or annual nutrient load.

1.1.1 Example Sources of Climate Change Information

Future climate change is expected to vary considerably in different regions of the country. Selected sources of climate change information, data, and guidance concerning the use of climate change data are listed below. Most of the sources listed below provide climate change projections developed from climate modeling experiments using GCM or coupled GCM/RCM models. Information from these and other sources may be used to develop scenarios for different regions of the U.S. Note that this is not an exhaustive list. Information and guidance about climate change in different parts of the country can be obtained from additional sources including local government agencies, universities, and other groups. Over time, additional information about climate change is also likely to become available as climate models are improved, new modeling experiments are conducted, and research such as investigations of paleo-climate better reveal historical patterns of climate variability.

IPCC Data Distribution Centre (DDC): http://www.ipcc-data.org/

Lawrence Livermore National Laboratory, Program for Climate Model Diagnosis and Intercomparison: http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php

Lawrence Livermore National Laboratory/Bureau of Reclamation/Santa Clara University: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html

North American Regional Climate Change Assessment Program (NARCCAP): http://www.narccap.ucar.edu/data/index.html

Consortium of Atlantic Regional Assessments (CARA; mid-Atlantic U.S. region): http://www.cara.psu.edu/climate/models.asp

University of Washington, Climate Impacts Group (northwest U.S. region): http://www.cses.washington.edu/data/ipccar4/

It must be noted that climate projections based on climate modeling experiments are not predictions, or the "most likely" future condition. Rather, these are projections of how future climate could change based on a specific set of assumptions adopted for a particular experiment (e.g. future greenhouse gas emissions) and including an element of uncertainty inherent in modeling a highly complex system. As discussed previously, water managers can assess their exposure to climate-related risks by considering the sensitivity of key management goals to a wide range of plausible climatic conditions and events. This information can then be used to guide decisions about appropriate management responses.

1.2 About This Document

The purpose of this report is to compile in a single document a variety of documentation and user support materials useful to BASINS CAT users. In addition to the current document, much of the material found in this report will be made accessible online in html format through the BASINS Version 4 help function.

This document is composed of 6 chapters:

- Chapter 1 is a brief summary of the background and general philosophy behind development of the BASINS CAT.
- Chapter 2 provides a "what and why" discussion of BASINS CAT capabilities.
- Chapter 3 addresses illustrates application of the tool through a series of hands-on tutorials.
- Chapter 4 provides additional basic information about the development and application of the tool in the form of a user's manual.
- Chapter 5 briefly describes a case study application of the BASINS CAT illustrating the use of the tool to assess the potential impacts of climate change on a mid-Atlantic watershed.
- Chapter 6 is a listing of additional resources for learning more about climate change and the potential impacts of climate change on water resources.

2.0 CAT Methods and Capabilities

The CAT development effort resulted from the need to provide tools and information to help water managers understand and manage the potential impacts of climate change on water resources at the watershed scale. This required a flexible approach for developing climate change scenarios, coupled with a robust watershed modeling system. EPA's BASINS modeling system is a widely know, well documented modeling system developed in the late 1990's to support watershed management. As such, the BASINS system provides a unique platform upon which additional capabilities for assessing the potential impacts of climate change on water and watershed systems can be developed.

BASINS provides a suite of watershed models, from sophisticated broad-spectrum watershed models to agricultural models to planning and management level models, plus supporting tools and data, all within one package. BASINS CAT is available for use with the Hydrological Simulation Program-FORTRAN (HSPF), a mathematical watershed model for simulating hydrologic and water quality processes in natural and man-made water systems. HSPF has been widely applied in the planning, design, and operation of water resources systems for well over a decade, and is arguably one of the best verified watershed models currently available.

Chapter 2 first introduces the BASINS modeling system and the HSPF watershed model. It then describes the capabilities for assessing the impacts of climate change on water and watershed systems provided by the Climate Assessment Tool.

2.1 BASINS

The U.S. Environmental Protection Agency's BASINS system (USEPA, 2007; http://www.epa.gov/waterscience/basins/) is designed to support watershed and water quality-based studies by facilitating access to environmental information, modeling and analysis tools, and providing an integrated framework for examining management alternatives. The BASINS system combines the following five components: 1) a comprehensive collection of national cartographic and environmental databases, 2) environmental assessment tools (to summarize results; establish pollutant source-impact interrelationships; and selectively retrieve data); 3) utilities (e.g., import tool, download tool, grid projector, post-processor, and land use, soil classification and overlay tool); 4) automated watershed characterization reports (for eight different data types); and 5) a suite of watershed models including HSPF (Bicknell et al., 2005), AQUATOX (Clough and Park, 2006), and PLOAD (USEPA, 2007). A recent EPA report, "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" (USEPA, 2005), found that among 37 current watershed models and modeling systems, BASINS contained the most robust suite of assessment capabilities (based on level of complexity, simulation time step, hydrologic regimes, water quality constituents and BMP simulation options).

This suite of models, support tools, and national environmental data provide an effective platform for conducting varied and complex studies of environmental stressors, watershed responses, and watershed management throughout the United States. The main interface to BASINS is provided through a Geographic Information System (GIS). Because GIS combines mapping tools with a database management system, it provides the integrated framework necessary to bring modeling tools together with environmental spatial and tabular data. Version 4.0 of BASINS is the first to be primarily based on a non-proprietary, open-source GIS foundation (http://www.mapwindow.org/). By using open-source GIS tools and non-proprietary data formats, the core of BASINS has become independent of any proprietary GIS platform while still accommodating users of several different GIS software platforms. The underlying software architecture provides a clear separation between interface components, general GIS functions, and GIS platform-specific functions. Separating these components and functions provides a future migration path for using core GIS functions from other GIS packages or for accommodating future updates to the already-supported GIS packages.

With its open-source plug-in framework and growing number of data sources, a number of new models and analysis tools have been and are being added to BASINS 4.0. On the modeling side of the system, a draft version of a plug-in for EPA's DFLOW model (USEPA, 2006a) has been developed and will be released in early 2008. Work on development of a plug-in for the Soil and Water Assessment Tool (SWAT) model (Arnold and Fohrer, 2005) will be completed by early 2009. Work has begun on development of a plug-in for EPA's Water Quality Analysis Simulation Program (WASP) model (USEPA, 2006b), and release is scheduled for 2008. Plans for a plug-in for the Stormwater Management Model (SWMM) (Rossman, 2007) have also been developed. A data analysis tool recently added to BASINS is the USGS Surface Water Statistics (SWSTAT) software (USGS, 2008), which is a software package for statistically analyzing time-series data. A BASINS plug-in now provides a user interface to functions including frequency distribution, trend analysis, and n-day annual time series.

Data sources available to BASINS users continue to expand. 2008 additions will include download and system interaction capabilities for NHDPlus (EPA & USGS's enhanced hydrography dataset - http://www.horizon-systems.com/nhdplus/), TerraServer (satellite and aerial imagery - http://terraserver-usa.com/), NLCD 2001 (national land cover dataset from the Multi-Resolution Land Characteristics Consortium - http://www.mrlc.gov/), and Modernized STORET (EPA's water quality, biological and physical dataset - http://www.epa.gov/storet/).

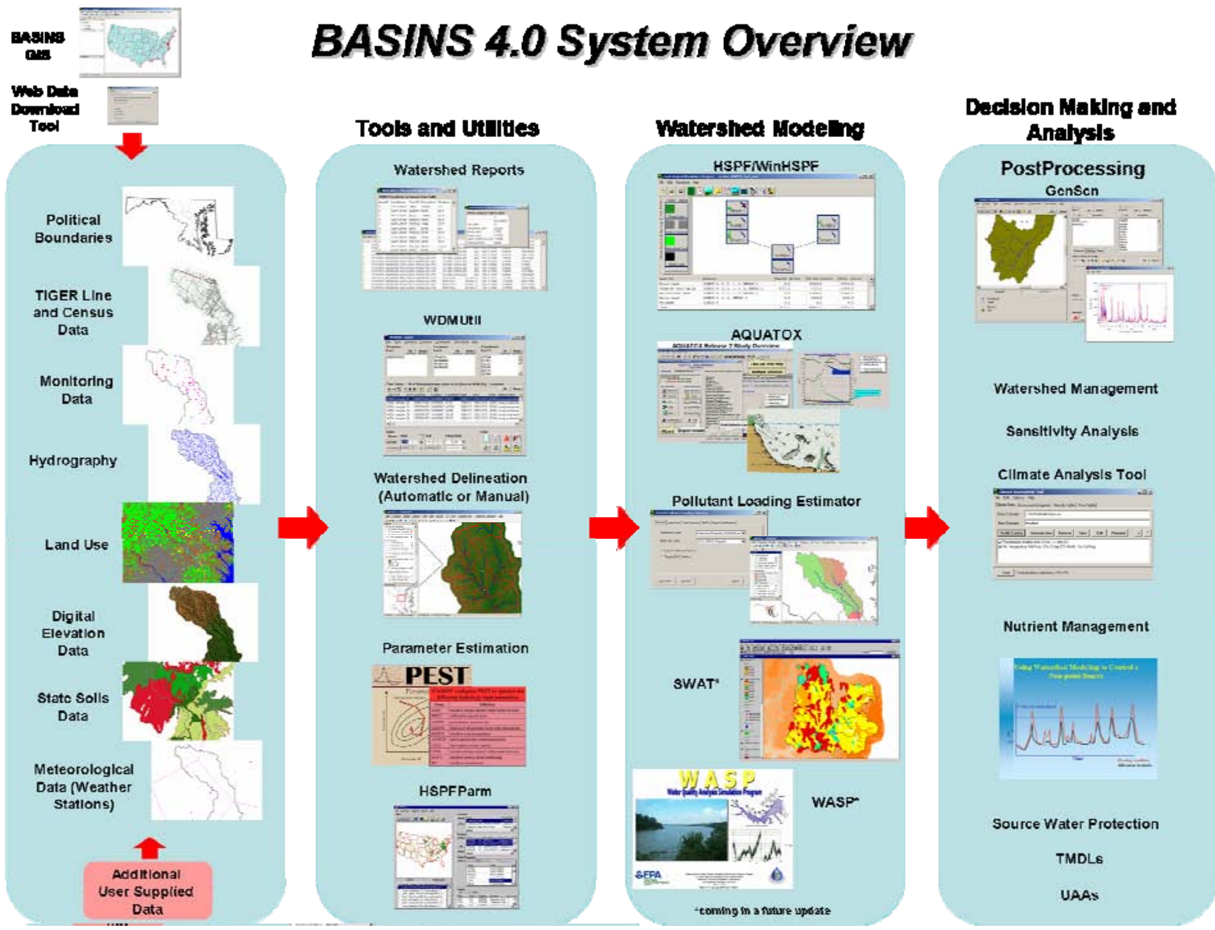


Figure 2-1. U.S. EPA BASINS Version 4.0 Integrated Modeling System

2.2 HSPF

BASINS CAT is currently available for use with the Hydrological Simulation Program-FORTRAN (HSPF) watershed model (Bicknell et al., 2005). HSPF is a mathematical model developed under joint EPA and USGS sponsorship for simulating hydrologic and water quality processes in natural and man-made water systems. HSPF is a well documented, broadly applicable analytical tool which has an established record of applications in the planning, design, and operation of water resources systems.

The HSPF model uses information on the time history of rainfall, temperature, evaporation, and parameters related to land use patterns, soil characteristics, and agricultural practices to simulate the processes that occur in a watershed. The initial result of an HSPF simulation is a time series simulation of the quantity and quality of water transported over the land surface and through various soil zones down to the groundwater aquifers. Runoff flow rate, sediment loads, nutrients, pesticides, toxic chemicals, and other quality constituent concentrations can also be predicted. The model uses these results and stream channel information to simulate instream processes. From this information, HSPF produces a time series simulation of water quantity and quality at any point in the watershed.

Simulating the watershed processes associated with wet-weather occurrences are particularly complex and require continuous/dynamic analyses of the hydrologic and quality processes associated with landscape and land activities together with in-stream fate and transport processes. HSPF offers a complete and defensible process-based watershed model for addressing water quality impairments associated with diffuse pollution. Although other watershed models are available, they are often limited to specific land uses or do not include in-stream response processes. The HSPF model can be configured to represent all types of land uses, offers the ability to include land use activities and potential management controls, allows for dynamic simulation, and a detailed representation of critical conditions associated with high flows and wet-weather conditions.

HSPF has been used extensively to assess the hydrologic and water quality impacts associated with land use/landcover change and implementation of watershed best different management practices (BMPs). Other potential applications include:

- Hydropower operations and dam removal studies
- River basin and watershed planning
- River restoration planning
- Storm drainage analyses
- Water quality planning and management
- Point and nonpoint source pollution analyses

- Soil erosion and sediment transport studies
- Evaluation of urban and agricultural best management practices
- Fate, transport, exposure assessment, and control of pesticides, nutrients, and toxic substances

HSPF can be applied to most watersheds using available meteorologic and hydrologic data; soils and topographic information; and land use, drainage, and system (physical and man-made) characteristics. The specific data requirements for running an HSPF simulation are:

1. Meteorologic data (for simulation period)
    a. Precipitation, (daily, hourly, or 15-minute values for small watersheds)
    b. Daily pan evaporation
    c. Daily maximum and minimum air temperature (needed for water temp and snow only)
    d. Total daily wind movement (needed for water temperature and snow only)
    e. Total daily solar radiation (needed for water temperature and snow only)
    f. Daily dewpoint temperature (needed for water temperature and snow only)
    g. Average daily cloud cover (needed for water temperature and snow only)

2. Watershed land use/land cover characteristics (preferably as GIS layers)
    a. Topographic map/data of watershed and subwatersheds, and/or DEM coverage
    b. Land use/cropping delineation and acreages (as GIS layer)
    c. Soils delineation and characteristics (GIS soils coverage of soil texture and/or SCS Hydrologic Soil Groups)
    d. Isohyetal map of mean annual rainfall (GIS layer preferred)

3. Hydrography and channel characterization
    a. Channel lengths, slopes, cross-sections and geometry, rating curves, or DEM of channel and overbank areas
    b. Channel bed composition (e.g. particle dist., nutrients, pesticides)
    c. Diversions, point sources, channelized segments, etc.
    d. Tributary area (and land use distribution) for each channel reach (or available from GIS land use layers)
    e. Waterbody/reservoir bathymetry (or stage-volume-surface area relationships), stage-discharge relationships, operational procedures, and spillway characteristics

4. Hydrologic and water quality observations (needed for model calibrations)

a. Flow rates during all monitored storm events
b. Flow volume/rate totals for storm/daily, monthly, annual
c. Snow depths (for areas with significant snow accumulation)
d. Sediment mass losses in runoff and sediment concentrations in runoff and receiving water
e. Chemical/constituent mass losses in runoff and concentrations in runoff and receiving water
f. Soil concentrations of constituent/nutrient forms, if available
g. Estimated/actual constituent concentrations in precipitation
h. Particle size distributions (sand, silt, clay fractions) of soils, eroded sediments, and channel bed sediments

While the data requirements running an HSPF simulation are fairly extensive, HSPF users benefit from a wide range of documentation and user support materials developed over decades of model applications and made available to HSPF users. Perhaps more importantly, HSPF has a relatively large number of parameters that need adjustment to properly calibrate the model. Assistance in setting model parameter values is available, however, from sources including the HSPF Application Guide (Donigian et al., 1984), an interactive database of parameter HSPF values used for previous model applications (Donigian et al., 1998), and in the form of Techical Notes available at the EPA BASINS web site.

HSPF contains three application modules that are used to simulate the hydrologic/hydraulic and water quality components of the watershed:

1. PERLND - Simulates runoff and water quality constituents from pervious land areas in the watershed.

2. IMPLND - Simulates impervious land area runoff and water quality.

3. RCHRES - Simulates the movement of runoff water and its associated water quality constituents in stream channels and mixed reservoirs.

PERLND simulates the water quality and quantity processes that occur on pervious land areas, and it is the most frequently used part of HSPF. To simulate these processes, PERLND models the movement of water along three paths: overland flow, interflow, and groundwater flow. Each of these three paths experiences differences in time delay and differences in interactions between water and its various dissolved constituents. A variety of storage zones are used to represent the processes which occur on the land surface and in the soil horizons. Snow accumulation and melt are also included in the PERLND module so that the complete range of physical processes affecting the generation of water and associated water quality constituents can be represented. Some of the many capabilities available in the PERLND module include the simulation of:

- water budget and runoff components

- snow accumulation and melt

- sediment production and removal
- accumulation and washoff of user-defined nonpoint pollutants
- nitrogen and phosphorus fate and runoff
- pesticide fate and runoff
- movement of a tracer chemical

IMPLND is used for impervious land surfaces, primarily for urban land categories, where little or no infiltration occurs. However, some land processes do occur, and water, solids, and various pollutants are removed from the land surface by moving laterally downslope to a pervious area, stream channel, or reservoir. IMPLND includes most of the pollutant washoff capabilities of the commonly used urban runoff models such as the Stormwater Management Model (SWMM).

One difference between PERLND and IMPLND process representation is of note. In the SOLIDS code section, IMPLND offers the capability to model the accumulation and removal of urban solids (i.e. solids on impervious areas) by processes which are independent of storm events (e.g., street cleaning, decay, wind deposition or scour). To use this option, the modeler needs to assign monthly or constant rates of solids accumulation and removal, estimate parameter values for impervious solids washoff (analogous to methods in the SEDMNT module of PERLND), and provide 'potency factor' values for constituents associated with the solids removed. Alternatively, the IQUAL module can be used to represent accumulation and removal processes for each constituent individually, analogous to the PQUAL approach.

The instream module of HSPF (named RCHRES) simulates the movement of runoff water and its associated water quality constituents in stream channels and mixed reservoirs. The module features individual compartments for modeling hydraulics, constituent advection, conservative (i.e., non-reactive) constituents such as total dissolved solids or chlorides, water temperature, inorganic sediment, generalized quality constituents, specific constituents involved in biochemical transformations, and acid mine drainage phenomena.

The model employs the following methods and capabilities. Additional detail on HSPF model capabilities and formulations is available in the HSPF User's Manual.

- Backwards finite difference solution scheme
- 1-D branching, uni-directional solution
- Flow routing technique by kinematic wave methods (momentum is not considered)
- Non-cohesive (sand) and cohesive (silt, clay) sediments are simulated; migration of each sediment fraction between suspension in water and the bed is modeled by balancing deposition and scour computations

- Code provides the user with the capability to model any subset of the following generalized processes: advection of dissolved material; decay of dissolved material by hydrolysis, oxidation by free radical oxygen, photolysis, volatilization, biodegradation, and/or generalized first-order decay; production of one modeled constituent as a result of decay of another constituent; advection of adsorbed suspended material; deposition and scour of adsorbed material; and adsorption/desorption between dissolved and sediment-associated phases.
- Detailed simulation of constituents involved in biochemical transformations. Included are dissolved oxygen, biochemical oxygen demand (BOD), ammonia, nitrite, nitrate, phosphate, phytoplankton, benthic algae, zooplankton, refractory organics, and pH.
- Primary dissolved oxygen and BOD balances simulated with provisions for decay, settling, benthic sinks and sources, re-aeration, and sinks and sources related to plankton.
- Primary nitrogen balance modeled as sequential reactions from ammonia through nitrate. Ammonia volatilization, ammonification, denitrification, and ammonium adsorption/desorption interactions with suspended sediment fractions considered; both ammonium and phosphate adsorption/desorption to suspended sediment fractions modeled using an equilibrium, linear isotherm approach.
- Three types of plankton - phytoplankton, attached algae and zooplankton. Phytoplankton processes include growth, respiration, sinking, zooplankton predation, and death; zooplankton processes include growth, respiration and death; and benthic algae processes are growth, respiration and death.
- Hydrogen ion activity (pH) calculated by either of two independent code sections: (1) compute pH by considering carbonate system equilibria, or (2) perform user-defined instream chemical computations to represent acid mine drainage and acid rain affected waters.

HSPF applications since its inception in 1980 have been worldwide and number in the hundreds, if not thousands; nearly all HSPF applications have included application of both the landscape (PERLND, IMPLND) modules and the receiving water (RCHRES) module (e.g. Donigian et al., 1983; Mulkey et al., 1986; Johanson, 1989; Linker et al., 1998; AQUA TERRA and HydroQual, 2001). Numerous HSPF applications have focused only on simulating watershed hydrology, however, a wide range of applications also address nutrient loading and other water quality issues. HSPFParm, an interactive database of HSPF model parameters, includes data for over 40 watersheds in 14 states (Donigian et al., 1998). The model has been applied to such diverse climatic regimes as the tropical rain forests of the Caribbean, arid conditions of Saudi Arabia and the Southwestern U.S., the humid Eastern U.S. and Europe, and snow covered regions of Eastern Canada.

2.2.1 Benefits and Opportunities Offered by CAT/HSPF Linkage

A range of physical, chemical, and biological processes interact in complex ways to influence water and watershed systems. The HSPF model has for decades provided a powerful tool for exploring and understanding the potential outcomes of changes in watershed land use, management, and other watershed stressors. Watersheds are known to be highly climate sensitive, and climatic drivers are key inputs required to run watershed simulations. BASINS CAT thus represents a simple extension of current modeling capabilities intended to facilitate the use of watershed models to explore and understand the impacts of changes in climate on watershed systems. BASINS CAT currently is available for use only with the HSPF watershed model. The conceptual basis of CAT, however, is not specific to the HSPF model and is easily transferable to any other watershed model.

HSPF was considered a good model to use with BASINS CAT because of its long and proven history, its use of relatively detailed (and thus potentially more sensitive to a wide array of subtle changes in climatic drivers) algorithms in simulations, and its broad applicability for simulating a wide range of hydrologic and water quality attributes in diverse watershed settings. For example, HSPF allows users to develop watershed models that represent an extensive mix of land uses and watershed best management practices (BMPs). The model can then simulate the combined effects on runoff resulting from changes in the amount, form, intensity, and seasonality of precipitation, as well as the potential for changes in runoff to affect different water quality endpoints. Finally, BASINS and the BASINS HSPF model have a long history of application to assessing the impacts of changes in watershed land use and watershed management practices. In combination with these existing capabilities, the climate assessment capabilities provided CAT provide users with an ability to assess the combined impacts of climate change, land use change, and management practices. In addition, this capability allows evaluation of the potential effectiveness of different adaptation options for coping with the future impacts of climate change. It should be noted, however, that BASINS CAT does not provide any additional capabilities for simulating the effects of changes in land use and management. The only capabilities in this area are those already available within BASINS.

The following is a list of features available within BASINS are available to support comprehensive watershed assessments.

WinHSPF - a GUI for HSPF applications useful for implementing other management changes (e.g. land use, point source, BMPs). To assess the combined impacts of management practices and climate change, the specific management practices must first be reflected in a revised HSPF UCI file. This UCI file may then be accessed by CAT to investigate the combined effects.

WDMUtil - a user interface for WDM files. This tool is particularly helpful in developing WDM files to store both input and output time series for use by HSPF.

GenScn - a post-processing tool for comparing scenarios. GenScn contains a wide array of output capabilities including data listing, graphical plots, and statistical analyses.

Since the release of BASINS 4.0 in 2007, it has been a long-term goal to simplify the system by incorporating these tools into the BASINS user interface. With the latest BASINS 4 update in the summer of 2008, most of the functionality found in WDMUtil and GenScn has been brought into BASINS. Work has begun on incorporating WinHSPF into BASINS also, but presently WinHSPF still provides the most comprehensive interface to HSPF.

Along with these tools, BASINS and its documentation also provide a comprehensive resource for calibration of the HSPF model. Users manuals, tutorial exercises, technical notes, and FAQs relating to all aspects of watershed modeling may be found on the BASINS web site: http://www.epa.gov/waterscience/BASINS/.

2.3 Climate Assessment Tool (CAT)

Water and watershed systems are influenced by the amount, form, seasonality, and event characteristics of precipitation, as well as temperature, solar radiation and wind that affect evaporative loss. Any change in climate may thus be reflected in key management targets such as duration flow events (e.g., 7Q10), maximum water temperatures, or nutrient or materials loads required to meet a TMDL or other water quality regulatory requirement.

The BASINS CAT essentially provides additional capabilities to BASINS users in 2 general areas; a flexible preprocessing capability for creating meteorological time series reflecting any user-determined change in temperature and precipitation for use as input to the HSPF model, and a post-processing capability for calculating management targets (endpoints) useful to water and watershed managers from model output.

BASINS CAT enables adjustments to historical records of only two meteorological data types, precipitation and air temperature. The adjusted records are contained within the same BASINS Watershed Data Management (WDM) file containing historical weather records. CAT provides a view/export capability that (1) displays the changes resulting from a specific adjustment or (2) saves the adjusted weather record as an ASCII file. It is important to note that CAT does not provide actual data on climate change for any particular region of the U.S. Rather, CAT simply provides a flexible capability for users to create meteorological data reflecting any type of change they wish to consider.

Users can adjust historical data using standard arithmetic operators applied monthly, seasonally or over any other increment of time. This flexibility allows adjustments to be made reflecting long term seasonal climate change, as well as short-term, year-to-year changes such as changes in the intensity of periodic drought. In addition, adjustments to a climate variable can also be applied uniformly to all “events”, or be selectively imposed only on those historical events that exceed (or fall below) a specified threshold. Future climate change is expected to result in an acceleration or ‘intensification’ of the hydrologic cycle, whereby a greater proportion of annual precipitation occurs as larger magnitude events (Groisman et al., 2005; IPCC, 2007). A general trend during the 20th century towards increasing precipitation intensity has already been shown throughout the U.S. (Groisman et al., 2005). The ability to selectively adjust only events within user-defined size classes allows climate change scenarios to be created reflecting these changes. Finally, CAT also provides a capability for users to create time series that contain more frequent precipitation events.

The post-processing capability provided by CAT allows users to calculate hydrologic or water quality endpoint metrics such as an x-year, y-duration high or low flow event, an annual water yields, or an annual pollutant load. This capability provides a unique opportunity for water and watershed managers to assess the impacts of climate change in terms of the metrics that are traditionally used for understanding impacts and making decisions within their specific professions or management domains (Johnson and Kittle, 2006). The user may select as endpoints any HSPF state variable or flux that is being modeled and output as a result of the model set up. If so desired, CAT enables users to further refine their analyses by considering only time periods of concern. Details for such applications are provided in Section 2.3.2.

BASINS CAT capabilities are seamlessly integrated into the BASINS system through a series of graphical user interfaces. Specifically, application of BASINS CAT requires the following:

- A pre-existing, calibrated HSPF application
- WDM file containing HSPF input meteorological time series
- Output file(s) to which HSPF results are output (WDM and/or Binary)

For an HSPF application developed within BASINS, these elements will be created and saved in the BASINS project associated with the application. For an HSPF application developed outside of BASINS, input meteorological time series must come from a WDM file referenced by the HSPF User Control Input (UCI) file. Similarly, output time series must be stored on either a WDM or HSPF Binary output file for use by CAT. For either of these cases, CAT will first reference the HSPF application's UCI file. The input meteorological time series and output results reference by the UCI file will then be loaded into BASINS for use by CAT. A tutorial demonstrating the setup of BASINS-CAT can be found in section 3.0.

Running an assessment using CAT requires defining one or more climate change scenarios and selecting watershed endpoints. After initiating a CAT session, CAT creates the necessary input files and manages all input and output from HSPF. In addition, CAT provides additional capabilities for automating the creation and running of multiple climate change scenarios. Section 2.3.3 provides guidance on the types of assessments that can be performed.

After running an assessment, a suite of tools for summarizing and visualizing results is available both within the CAT interface as well as through standard BASINS plotting tools. Included among these are options for exporting tabular data summaries, creating and exporting pivot tables, and plotting time series. These tools are described in Section 2.3.4.

2.3.1 Tools For Developing Climate Change Scenarios

The following definitions apply throughout this report. Definitions of the terms projection, prediction, and scenario are from the Intergovernmental Panel on Climate Change (IPCC, 2007). The terms “scenario component” and “record adjustment” are defined with specific reference to this report and the BASINS CAT tool.

Projection. A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from predictions in order to emphasize that projections involve assumptions concerning, for example future socioeconomic and technological developments that may or may not be realized, and therefore are subject to substantial uncertainty (IPPC, 2007).

Prediction. A climate prediction (or forecast) is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or long-term time scales. Since the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature (IPPC, 2007).

Scenario. A scenario is a plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline (IPPC, 2007)

Scenario component. In the context of BASINS CAT, climate change scenarios are composed of one or more specific types of change, or scenario components. For example, a single climate change scenario could be defined to include increased precipitation during winter months, decreased precipitation during summer months, and a uniform annual increase in air temperatures. In the example above, the scenario is composed of 3 scenario components. BASINS CAT allows users to create complex climate change scenarios by specifying multiple scenario components (as arithmetic adjustments to baseline temperature and/or precipitation records), and assembling scenarios from one or more scenario components as desired.

Record adjustment. The term record adjustment refers to a specific arithmetic or other operation carried out on a temperature or precipitation record (time series) to reflect a specific scenario component. For example, a scenario component calling for 20% increase in winter precipitation can be represented by adjusting (here multiplying) each winter precipitation value in the baseline precipitation record by 1.2.

Scenarios representative of a range of potential changes in future climate can be created using the CAT interface by making one or more adjustments to a selected historical precipitation and/or air temperature record. A range of changes can be applied to historical time series reflecting different types of climate change (e.g. seasonal temperature changes, annual precipitation totals, high intensity precipitation events), and specific changes can then be assembled to create climate change scenarios for assessment. When climate change scenarios include adjustments to air temperature, CAT automatically re-generates the evapotranspiration record to reflect the specified changes in temperature. CAT can be used to create and run single climate change scenarios. In addition, CAT can be used to automate the creation and running of multiple "synthetic" scenarios within a specified range of values for selected change variables (IPCC, 2007).

The following sections describe different options for adjusting precipitation time series (Section 2.3.1.1), and air temperature time series (2.3.1.2). A discussion of combining individual adjustments to time series to create a climate change scenario is provided in Section 2.3.1.3. The discussion of climate scenario development concludes with additional information related to using CAT to define synthetic scenarios in Section 2.3.1.4.

2.3.1.1 Modify Historical Precipitation Records

Future climate change may result in complex changes in precipitation including changes in annual totals, seasonality, snowfall, the intensity of events, the length of dry spells, and other specific types of change (IPCC, 2007). Different hydrologic and water quality endpoints are more or less sensitive to specific types of precipitation changes. A complete understanding of the impacts of climate change on water and watershed systems thus requires the ability to represent and evaluate a variety of types and magnitudes of climate change.

BASINS CAT allows adjustments to be made to a historical precipitation record by one or more of the five methods below:

1. Apply a constant multiplier to all values in a precipitation record (e.g. a daily or hourly precipitation total); the assumption is that precipitation will change in a uniform way throughout each year of the full record, either increasing or decreasing by a uniform percent (multiplier).

2. Apply a constant multiplier only to values within a user-specified month or season of each year of the full record; the assumption is that precipitation will change only during a certain month or season of each year in the full record.

3. Apply a constant multiplier only to values within a user-specified range of years contained within the full record; the assumption is that that precipitation will change only during certain years within the full record, e.g. adjustment is made to a user-specified period of 10 years within a 30-year historical record.

4. Add or remove precipitation events to a historical precipitation record to represent changes in the frequency of events; the assumption is that changes in annual precipitation totals occur due to changes in the frequency of precipitation events.

5. Apply a constant multiplier only to values within a user-specified event size class (precipitation amount), e.g. change only those values that exceed or fall below a specified event ranking such as the largest 10 percent of events; the assumption is that climate change results in an intensification of the hydrologic cycle, whereby a larger proportion of annual precipitation occurs as heavy precipitation events (Groisman et al., 2005).

Each of these five options for adjusting precipitation records is described below. For each potential adjustment, an example is given of a question or analysis that might be addressed by imposing the adjustment on the baseline historical precipitation record. Directly following the analysis question, the specific CAT capability that has been implemented is described. The information provided in this section is limited to describing approaches and capabilities for making adjustments to precipitation records. Chapter 3 provides a suite of tutorials that provide the “how to” instructions for building and using modified historical precipitation records. Chapter 4 provides a user’s manual that details all user options.

2.3.1.1.1 Apply Multiplier to Full Record

Example of a relevant question/analysis: Evaluate the impact of a uniform 20 percent increase in precipitation on watershed endpoints.

The simplest (and coarsest) method of modifying precipitation is to apply a multiplier to historical values over the entire span of the model run. This method can be used in a stand-alone manner, or as one component of a more complex scenario that includes additional adjustments. As a stand alone-adjustment, application of a constant multiplier might be performed in situations where previous studies do not make a convincing argument that precipitation changes exhibit seasonality, variable changes from year to year, changes in storm frequency or intensification of storms. As a component of a scenario that includes multiple adjustments, any of the change types described above could be superimposed on a uniform increase or decrease of historical precipitation. For example, one might apply half of an increase in precipitation uniformly and impose the other half in only the largest storms.

2.3.1.1.2 Apply Seasonal Multiplier

Example of a relevant question/analysis: Evaluate the impact on watershed endpoints of a uniform 20 percent seasonal increase in precipitation during the months of June, July and August for each year of the record.

Climate change is expected to vary seasonally throughout the year in most regions of the U.S. For example, greater increases in precipitation are anticipated during winter months in the northeast U.S. than at other times of the year. A seasonal adjustment to a historical record is achieved by specifying and applying a multiplier to only records within a specific, user defined yearly time interval or ‘season’. To define a season, CAT enables the selection of one month, or any combination of months.

2.3.1.1.3 Modify Partial Record

Example of a relevant question/analysis: Evaluate the effect of climate change-induced drought by decreasing by 20 percent all precipitation values occurring within the driest water year contained within the record.

Climate change is expected to result in an increased severity of drought in many parts of the U.S. This type of change can be represented in a climate change scenario by adjusting historical precipitation values during specified, consecutive periods of time. For example, investigating the impacts of increasing drought may include decreasing the precipitation total for an already low-rainfall year. Using CAT a single multiplier can be applied to precipitation data during a specified portion of the historical precipitation record. The user may define the period that will be adjusted in terms of either calendar years or water years (i.e., October to October).

2.3.1.1.4 Represent Storm Intensification

According to IPCC (2007), "It is likely that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over the past 50 years over most land areas." CAT enables representation of this phenomenon at a watershed scale, either in a stand-alone analysis, or as a component of a more complex climate scenario.

Example of relevant questions/analyses:

(1) Evaluate the impact on watershed endpoints of a 10 percent increase of annual precipitation occurring only within the largest 20% (defined by total storm volume) of the storms present in the historical precipitation record; (2) Evaluate the impact on watershed endpoints of a 10 percent decrease in precipitation occurring only in events within the historical record that are among the lowest 90% defined by total storm volume.

Using CAT a constant multiplier can be applied only to specific rainfall events that exceed or fall below a user-specified storm volume ranking (e.g., largest 10 percent or smallest 50 %). This capability allows changes to be imposed only on selected events within user-defined size classes, and can be used to represent the projected effects of intensification of the hydrologic cycle, whereby an increased proportion of annual rainfall occurs during larger magnitude events.

Implementing this type of adjustment to a historical precipitation record requires specification of a change in precipitation volume resulting from the intensification adjustment, and specification of the particular storm events within which this volume is distributed. More specifically, the user must:

1. Specify a percent change in water volume over the entire precipitation record (or for a season within each year)

2. Specify which storm events are to be adjusted using the following criteria (note the criteria below include options for specifying what an "event" is as well as for specifying an event intensity threshold):

    a. An event intensity threshold
    b. The maximum allowable length of time (hours) that the intensity threshold is <u>not achieved</u> before one event concludes and another begins,
    c. The minimum volume that a storm event must have to be considered a candidate for adjustment, and/or
    d. The minimum duration that a storm event must have to be considered a candidate for adjustment.

3. Further reduce the collection of storms that will be adjusted (as per #1 above) by specifying the percentage of the total volume of the rainfall record that is to reside in the storms that are included in the adjustment.

Given this information, CAT then computes (1) the total volume of rainfall to be added/removed from the selected storms, and based on this value (2) a multiplier that will be applied uniformly to each selected rainfall event to distribute the desired change in precipitation volume.

A Synoptic Analysis Tool is also available within the BASINS system (BASINS 4.0) that can be used characterize precipitation events. This application may be useful to BASINS CAT users to define event size classes and other relevant information prior to specifying adjustments using CAT. The Synoptic Analysis Tool can be applied directly, in a stand-alone manner, to any weather record and provides a capability to sort or group storm events based on volume (max, sum, mean, cumulative), event duration (max, sum, mean, standard deviation), event intensity (max, mean, standard deviation), and the elapsed time since the last event (max, mean, variance)

2.3.1.1.5 Add or Remove Storm Events

Example of a relevant question/analysis: Evaluate the impact on watershed endpoints of increasing precipitation volume by 10 percent (in terms of volume) by adding randomly timed rainfall events with an average intensity greater than 0.1 inches per hour.

CAT enables users to represent changes in the frequency of precipitation events by randomly selecting and duplicating with a historical time series (adding) an existing event, or randomly selecting and removing an existing event from a historical record. More specifically, implementing this type of adjustment to a historical precipitation record requires the following steps:

1. Specify a percent change in water volume over the entire precipitation record (or for a season within each year)

2. Specify which storm events will be either duplicated (to increase total precipitation volume) or eliminated (to decrease total precipitation volume); storm events may be defined in terms of any or all of the following attributes:

    a. An event intensity threshold,
    b. The maximum allowable length of time (hours) that the intensity threshold is not achieved before one event concludes and another begins,
    c. The minimum volume that a storm event must have to be considered a candidate for adjustment, and/or
    d. The minimum duration that a storm event must have to be considered a candidate for adjustment.
3. Given this information, CAT randomly selects precipitation events for removal or duplication elsewhere in the record until the specified change in precipitation volume is reached.

When duplicating storm events, the position in the time series (i.e. the day(s) on which a new event is added) is determined randomly. Accordingly, it is possible for new events to overlap existing events. In such cases the new precipitation is simply added to existing precipitation for that time interval (e.g. day). CAT maintains an internal record to avoid duplicating the same storm twice, unless all qualifying storms have been duplicated prior to meeting the specified volume increase.

2.3.1.2 Modify Historical Air Temperature Records and Regenerate Evapotranspiration Record

Air temperatures in the Northern Hemisphere during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years, and likely the highest in at least 1300 years (IPCC, 2007). The sensitivity of different hydrologic and water quality endpoints to changes in temperature is likely to vary. A complete understanding of the impacts of climate change on water and watershed systems thus requires the ability to represent and evaluate a variety of types and magnitudes of changes in temperature.

The potential influence of warming temperatures on evapotranspiration and watershed biogeochemical cycling are particularly pronounced. Evapotranspiration is a major factor in the hydrological cycle and has a strong effect on watershed hydrologic response. It is extremely important to note that whenever an adjustment is made to a historical air temperature record using CAT, the potential evapotranspiration (PET) record used by HSPF must be re-generated to reflect the new air temperature values. HSPF uses the Hamon (1961) method for estimating the potential evapotranspiration based on air temperature. It is very simple to re-generate PET values to reflect modified air temperatures when running a simulation through the CAT interface. However, re-generation of PET is not an automatic function in CAT - it is the user's responsibility to instruct CAT to perform the re-generation of PET.

Using CAT, changes can be imposed on a historical air temperature record by one or more of the three methods below:

1. Apply an incremental or decremental value to all air temperature values in the historical record; the assumption is that one component of the climate change is constant throughout the year, either increasing or decreasing each air temperature event by a specified value.

2. Apply an incremental or decremental value to all air temperature values within a user-specified season each year of the full record; the assumption is that one component of the climate change imposes a uniform increase or decrease in all air temperature values within a season each year, but does not change the air temperature record for the rest of each year.

3. Apply a constant to a user-specified period of the historical record; the assumption is that one component of climate change is that year to year (or period to period) variability in

air temperature will occur (i.e. some periods will remain consistent with historical behavior, while others will not).

Each of these three options for adjusting air temperature records is described below. For each potential adjustment, an example is given of a question or analysis that might be addressed by imposing the adjustment on the baseline historical air temperature record. Directly following the analysis question, the specific CAT capability that has been implemented is described. The information provided in this section is limited to describing approaches and capabilities for making adjustments to air temperature records. Chapter 3 provides a suite of tutorials that provide the "how to" instructions for building and using modified historical air temperature records. Chapter 4 provides a user's manual that details all user options.

2.3.1.2.1 Apply Increment or Decrement to Full Air Temperature Records and Regenerate Evapotranspiration Record

Example of a relevant question/analysis: Evaluate the impact of a uniform 2 degree Fahrenheit increase in air temperature on watershed endpoints; account for effects of temperature change on potential evapotranspiration.

The simplest method of modifying air temperature is to add or subtract a constant value from all historical values over the entire time interval of the model run. This adjustment can be performed in a stand-alone manner, or as one component of a more complex scenario that includes additional adjustments. As a stand alone-adjustment, application of a uniform increment or decrement might be performed in situations where previous studies do not make a convincing argument that air temperature changes exhibit seasonality or variable changes from year to year. As a component of a scenario that includes multiple adjustments, either of the other two change types described above could be superimposed on a uniform increase or decrease of historical air temperature. For example, one might apply half of an increase in air temperature uniformly and impose the other half in only the summer months.

2.3.1.2.2 Apply Seasonal Increment or Decrement to Air Temperature Records and Regenerate Evapotranspiration Record

Example of a relevant question/analysis: Evaluate the impact on watershed endpoints of a uniform 2 degrees Fahrenheit seasonal increase in air temperature during the cool months (November through April) and a uniform 4 degrees Fahrenheit increase during the warm months (May through October); account for effects of temperature change on potential evapotranspiration.

As with precipitation, CAT enables the modification of temperature (and computed PET) values for a specified portion of the year. With many climate models predicting larger temperature increases (in total degrees) in warmer months than in cooler, this capability can be very useful in representing varying patterns throughout the year.

A seasonal adjustment to a historical record is achieved by specifying and adding or subtracting a constant value to all air temperature values that occur within a user-defined ‘season’ throughout the record. To define a season, CAT enables the selection of one month, or any combination of months.

When making a seasonal adjustment to an air temperature record, it is the CAT user’s responsibility to instruct CAT to re-generate the potential evapotranspiration file that HSPF will use for watershed simulation in parallel with the modified air temperature record.

2.3.1.2.3 Adjust Partial Record and Regenerate Evapotranspiration Record

Example of a relevant question/analysis: Evaluate the effect that a uniform increase of 3 degrees Fahrenheit has on drought conditions occurring within the driest water year contained within the simulation period; account for effects of temperature change on potential evapotranspiration.

Investigating the impacts of increasing drought severity may, for example, require increasing the air temperature values and re-computing PET values for a single, specified year within a historical record. Using CAT a uniform increment or decrement can be applied to air temperature values during a specified portion of the historical air temperature record. The user may define the period that will be adjusted in terms of either calendar years or water years (i.e., October to September).

When making an adjustment to a portion of an air temperature record, it is the CAT user’s responsibility to instruct CAT to re-generate the potential evapotranspiration file that HSPF will use for watershed simulation in parallel with the modified air temperature record.

2.3.1.3 Combine multiple adjustments to create a climate change scenario

Example of a relevant question/analysis: Evaluate the impact on watershed endpoints that results from combining the following adjustments to the historical records:

1. 20 percent increase in summer (June through August) precipitation,
2. 2 degree Fahrenheit increase in air temperature during the ‘cool’ season (November through April) and
3. 4 degree Fahrenheit increase in air temperature during the ‘warm’ season (May through October).

BASINS CAT provides a listing of all adjustments that the user has defined for precipitation and air temperature records as one of its user interface screens. Each adjustment is preceded by a ‘checkbox’ that enables the user to indicate those adjustments that are to be included as components for simulation of a particular scenario (or series of synthetic scenarios). The user may use the checkboxes to sequentially specify and simulate scenarios that combine various combinations of previously defined adjustments.

2.3.1.4 Create Synthetic Climate Change Scenarios

The IPCC-TGIA suggests analyses using synthetic scenarios as a useful approach for understanding environmental sensitivity to climate change (IPCC-TGIA, 2007). Synthetic scenarios describe techniques where particular climatic attributes are changed by a realistic but arbitrary amount, often according to a qualitative interpretation of climate model simulations, historical variability, or other available information for a region. Application of this approach involves picking a range of values and step interval for one or more climate variable(s), and then creating and running scenarios based on each possible combination of arbitrarily assigned changes.

Example of a relevant question/analysis: Evaluate the sensitivity of watershed endpoints to changes in historical air temperature from 1 to 3 degrees F (at step interval of interval 1 degree F; equals changes of +1, +2 and +3 degrees F) and historical precipitation from 10 to 30 percent (at step interval of 10 percent; equals changes of 10, 20 and 30 percent); account for effects of temperature change on potential evapotranspiration.

BASINS CAT provides an explicit capability for conducting analyses using synthetic scenarios. CAT users can specify the type and range of climatic variability to be considered, and a step interval within the range to be considered. CAT then iteratively creates and manages the meteorological inputs, runs the watershed model (hydrology and water quality), manages model output, and provides tabular summaries of the response of selected endpoints. Any adjustment that can be performed using the single-run adjustment capabilities of CAT (i.e., those described in Sections 2.3.1.1 through 2.3.1.2) can also be performed within a series of synthetic runs. Hence, seasonal changes (via month specifications) repeated each year or changes to a specific whole year can be made. Results from a series of model runs can be analysed by exporting model output for use with any statistical or graphics package.

As stated previously, it is important to note that when synthetic scenarios include adjustments to air temperatures, CAT user’s must instruct CAT to re-generate the potential evapotranspiration file used by HSPF in watershed simulations.

2.3.1.5 Exporting CAT Climate Change Scenarios as Text (ASCII) Files

BASINS CAT seamlessly links capabilities for modifying historical weather data to create climate change scenarios with the HSPF watershed model within the BASINS system. It is possible, however, that some users may wish to create climate change scenarios using BASINS CAT for use with other models outside of the BASINS system. To provide this functionality, BASINS CAT offers two options for exporting climate change scenarios as ASCII text files:

1. In cases where a single adjustment is made to a precipitation or an air temperature record, the resulting record can be exported as an ASCII file independent of running the HSPF model.

2. In cases where multiple adjustments are made to a precipitation or an air temperature record, it is necessary to complete a HSPF model run for one or more environmental endpoints. After this has been accomplished, CAT enables the export of either or both of the precipitation and air temperature records that resulted from the multiple adjustments performed in defining the climate change scenario; again the export is performed in the form of ASCII files.

2.3.2 Tools for Assessing Environmental Endpoints

The post-processing capability within BASINS CAT to calculate hydrologic and water quality endpoints from model output time facilitates to the assessment of climate change impacts in terms of metrics that are traditionally used for understanding impacts and making decisions within their specific professions or management domains. For some investigations, simple outputs from the HSPF model such as annual sediment or nutrient loads provide the most effective metric. In other cases, a more relevant metric can be computed using standard model output. A post-processing capability has been developed for CAT that calculates numerous derived metrics such as x-year, y-duration high or low flow event. This post-processing capability allows and greatly facilitates assessments to be conducted for key management targets (Johnson and Kittle, 2006).

This section describes the range of endpoints that can be evaluated using CAT (Section 2.3.2.1) and describes CAT's ability to refine the analysis and reporting of impacts on watershed endpoints by specifying "value ranges of concern (Section 2.3.1.2)" and "time periods of concern (Section 2.3.1.3)".

The information provided in this section is limited to describing approaches and capabilities for making adjustments to precipitation records. Chapter 3 provides a suite of tutorials that provide the "how to" instructions for specifying environmental endpoints. Chapter 4 provides a user's manual that details all user options.

2.3.2.1 Endpoint Options

BASINS CAT users can specify endpoints to be calculated by selecting parameters (i.e. an output HSPF time series) and attributes of parameters to be calculated (e.g. mean, min, max, 100-yr flood, 7Q10, etc.). The parameter options are determined by what is included in the output from an HSPF simulation, or more specifically the time series specified as output in the HSPF User Control Input file. Endpoint parameter options can be as simple as a few outputs to WDM data sets in the External Targets block, or can be greatly expanded by using the binary output file.

Once a CAT application has been set up, the endpoint options are provided to the user in scroll down menus on one or more screens. After selecting a parameter for calculating an endpoint, a set of parameter attributes common to all time series in BASINS is available. Within the CAT interface, the following parameter attributes are listed in a drop down menu:

- Min
- Max
- Sum
- Average annual sum of values
- Mean
- Geometric Mean
- Variance
- Standard Deviation
- Standard Error of Skew
- Serial Correlation Coefficient
- Coefficient of Variation
- 7Q10
- 100 year flood

2.3.2.2 Specify Value Ranges of Concern

In many cases water and watershed managers may be interested in endpoint values relative to some critical range or threshold value. Examples include a low flow threshold below which a fish species is subject to harm, or numeric State water quality standards for chemical endpoints. BASINS CAT provides a capability to visually flag endpoint values of concern within the Results table tab (Section 2.3.4.1). Users have the ability to flag endpoint values using one of two different schemes; a 'low range-favorable range-high range' color scheme, or a 'favorable range-outside of favorable range' color scheme. The first shading scheme corresponds to the default setting for shading, which is blue for cells with values falling below the favorable range, no shading for cells with values falling within the favorable range, and red for cells with values greater than the favorable range. The threshold/range that will be indicated as favorable is determined by the user.

2.3.2.3 Specify Time Periods of Concern (Seasonal and/or Partial Records)

Water and watershed managers may also be interested in endpoint values during only a particular season of each year or during a specific year (or water year) within the record. BASINS CAT provides an option to show in the Results table only those endpoint values falling within the period of concern. The time period of concern is determined by the user.

2.3.3 Running a HSPF Simulation Using BASINS CAT

Watershed simulations using HSPF can managed from within the BASINS CAT interface after creating and selecting the climate change scenarios to be considered (Section 2.3.1), and specifying the endpoints to be calculated (Section 2.3.2). Subsequent to running an assessment, CAT users may choose to either export simulation results for analysis or visualization using external software (e.g., MS Excel), or use existing tools within the BASINS system to create expanded summaries and visualization. The following section describes additional tools within BASINS for displaying and analyzing the results of HSPF simulations that may be useful to CAT users. All HSPF simulation results generated using CAT may also be exported as ASCII text files for use with other analysis and visualization software.

2.3.4 Tools for Summarizing and Visualizing Results

The information provided in this section is limited to describing approaches and capabilities for summarizing and visualizing results. Chapter 3 provides a suite of tutorials that provide the "how to" for displaying results. Chapter 4 provides a user's manual that details all user options.

2.3.4.1 Results Tables

Results tables are the most straightforward method available for reporting the results of HSPF simulations conducted with the CAT, including calculated endpoint values. The Results table contains values for each endpoint selected by the user (i.e. for each attribute (e.g. mean, min) of each HSPF output parameter (e.g, streamflow, sediment load) selected as an endpoint). The process for generating a results table is explained in a tutorial in Section 3.4.3.

2.3.4.2 Pivot Tables

In addition to reporting results in the Results table, BASINS CAT also provides a capability for visualizing and analyzing results of HSPF simulations using a pivot table. A pivot table is a powerful data visualization and analysis tool available in several commercial spreadsheet software programs (e.g., Microsoft Excel, OpenOffice.org). A pivot table can be used to quickly and easily assess relationships among multiple variables. The user sets up and changes the appearance of a pivot table by selecting a variable of concern and variables to use as x and y axes of the pivot table. Values of the variable of concern at each x,y coordinate location are then shown as a function of the x and y coordinate variables. A pivot table is similar in concept to a contour plot (x and y axis are the same), but expresses its information in the form of tabular numbers rather than graphical contour lines. The process for generating pivot tables is explained in Section 3.4.2.

2.3.4.4 Additional BASINS Tools

The time series results for HSPF simulations performed in conjunction with CAT may be displayed or further analyzed by using any of the following BASINS capabilities:

- Graph a time series or multiple time series
- Display attributes and calculated statistics in the form of a data tree (a method of displaying attributes and data in logical groups that can be collapsed or expanded with the "+" and "-" boxes built into the tree).
- Compute frequency statistics such for specified n-day values and recurrence intervals
- Calculate and display statistics for user-defined “seasons“
- Generate one time series from one or multiple other time series, such as performing unit conversions or mathematical operations (e.g. adding a number of time series)
- Create a separate time series consisting of each event exceeding a threshold, such as each storm event with hourly precipitation exceeding 2.0 inches

2.3.5 Using Scripts to Automate CAT Applications

Both BASINS and MapWindow, the GIS framework upon which BASINS is built, are open-source software products. This means that both programs and their source code may be downloaded free of charge without any run-time licenses required. The software architecture of the programs has been designed to readily allow end users to extend the programs. One way that this may be done is through the use of scripts. MapWindow and BASINS have both been developed in the .Net framework, meaning any script developed in a .Net language may be run from BASINS. Scripts provide an efficient and reproducible method for performing repetitive tasks. Scripts can be used to perform all facets of CAT analysis. A sample script and demonstration of how scripts are run is found in Section 3.5.

3.0 Tutorials

These Climate Assessment Tool (CAT) tutorials are designed to demonstrate a range of the tool's features, from simple to complex. For this reason the tutorials are divided into a series of small sessions that exhibit specific features. There is an overarching flow to the tutorials from beginning to end of typical CAT usage and the tutorials are organized in chronological groupings. Each tutorial provides the context of where that session's features fit into the CAT application process.

NOTE: The data shown in the tutorials is for demonstration purpose only and does not represent calibrated model results.

The tutorials are also organized in a parallel structure to Chapter 2, **Tools and Methods**. Where chapter 2 provides a theoretical description of CAT features and why they were developed, the tutorials provide detailed instruction on how to use the features. Thus, for example, each precipitation modification feature described in Sections 2.3.1.1.1 through 2.3.1.1.5 has a corresponding tutorial (Sections 3.1.1 through 3.1.5) with a sample application of the feature.

The overall organization of the tutorials is as follows:

1. BASINS-CAT Set-up
2. Developing Climate Change Scenarios
3. Specifying Environmental Endpoints
4. Running a CAT Assessment
5. Summarizing and Visualizing Results

NOTE: The BASINS-CAT Set-up tutorial at the end of this section must be run before any of the other tutorials.

With the exception of the BASINS-CAT Set-up tutorial, there is a great deal of flexibility in how the tutorials may be run. The sections listed above contain multiple tutorial sessions that demonstrate various capabilities. It is not necessary to run every tutorial session although later sessions under Running an Assessment and Summarizing and Visualizing Results may reference climate change scenarios and environmental (hydrologic and water quality) endpoints developed in earlier sessions. To make this clear to the user, each tutorial will list any tutorials that must be run prior to it.

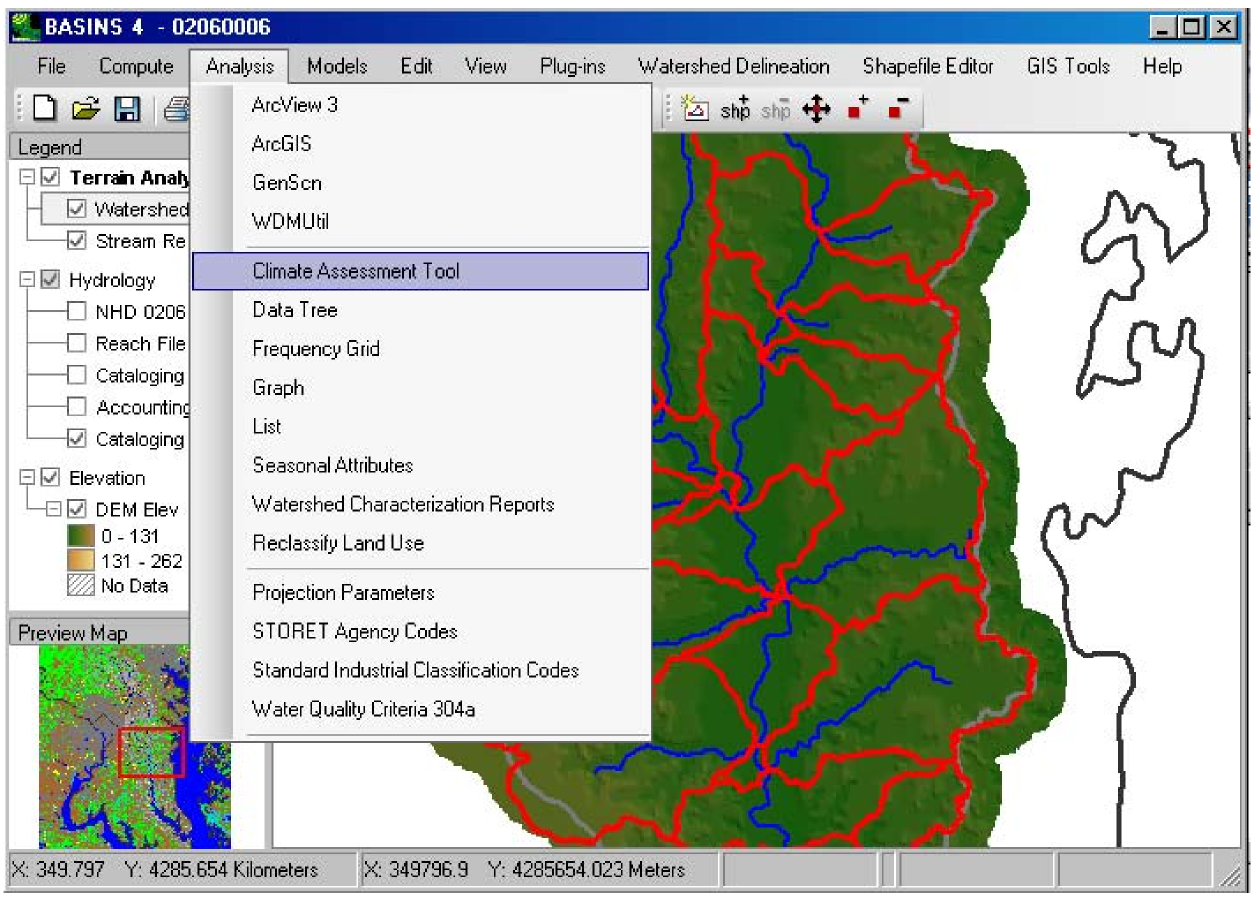
BASINS-CAT Setup

This session illustrates how to reference CAT from within BASINS and the initial steps required to begin climate change assessment. The steps in this session must be performed a single time prior to running any other tutorials.

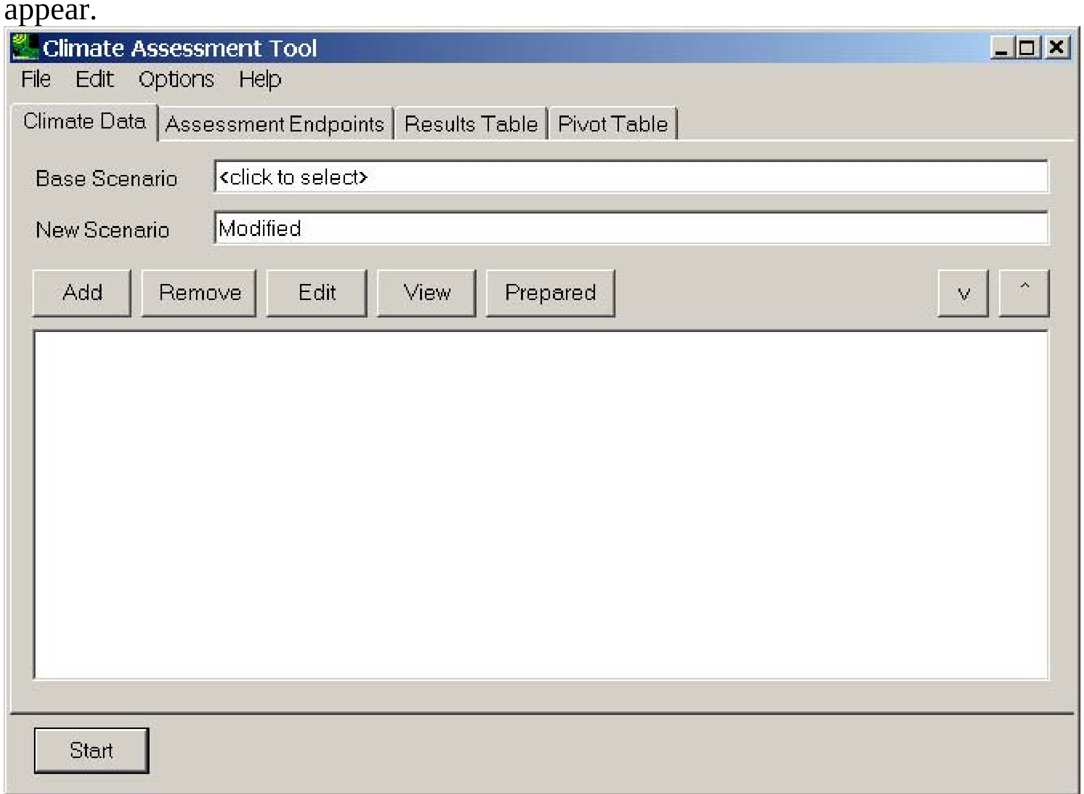
Before beginning this session, it is necessary to review the elements required for using CAT:

- A calibrated HSPF application
- WDM file containing HSPF input meteorological time series
- Output file(s) to which HSPF is outputting results (WDM or Binary)

Data used in the tutorials are taken from the sample files provided with the BASINS installation package. These files are found in the \BASINS\data\Climate folder. The BASINS system is mostly comprised of various software plug-ins, of which CAT is one. The first step in setting up CAT to run in BASINS is to be sure it is loaded as a plug-in. Select **Climate Assessment Tool** from the **Plug-ins:Analysis** submenu so that it has a check next to it. This will add **Climate Assessment Tool** to the **Analysis** menu.

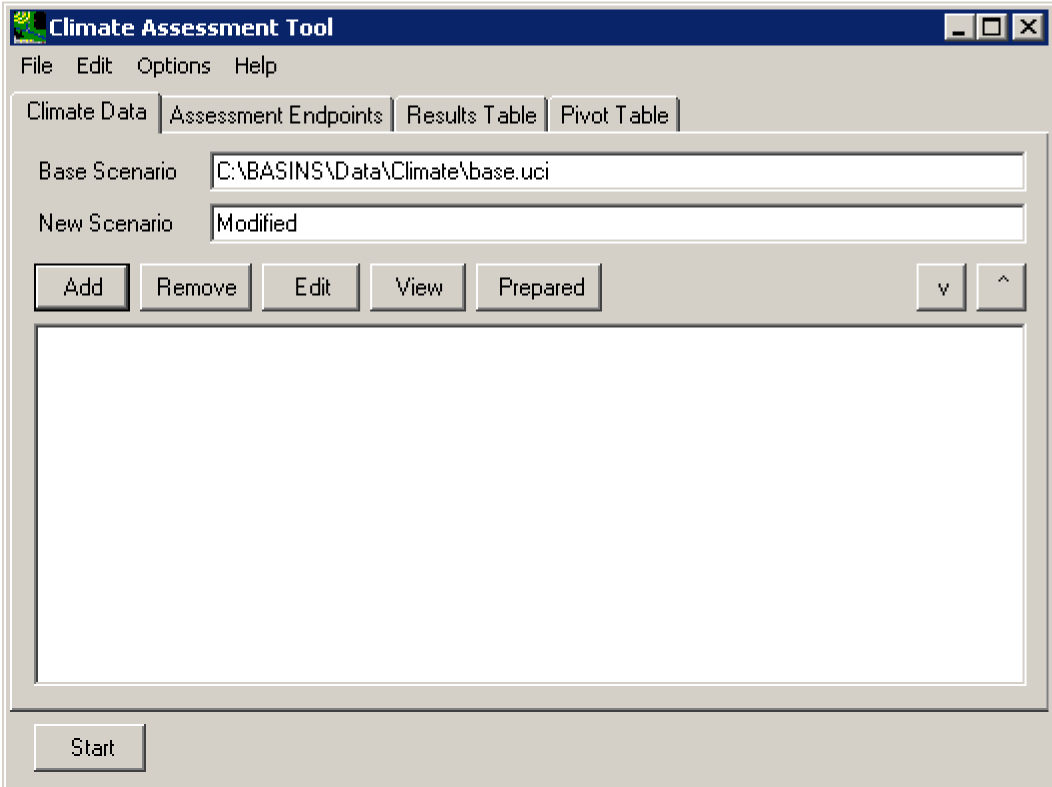


1. Select the **Analysis:Climate Assessment Tool** menu option, and the following form will appear.



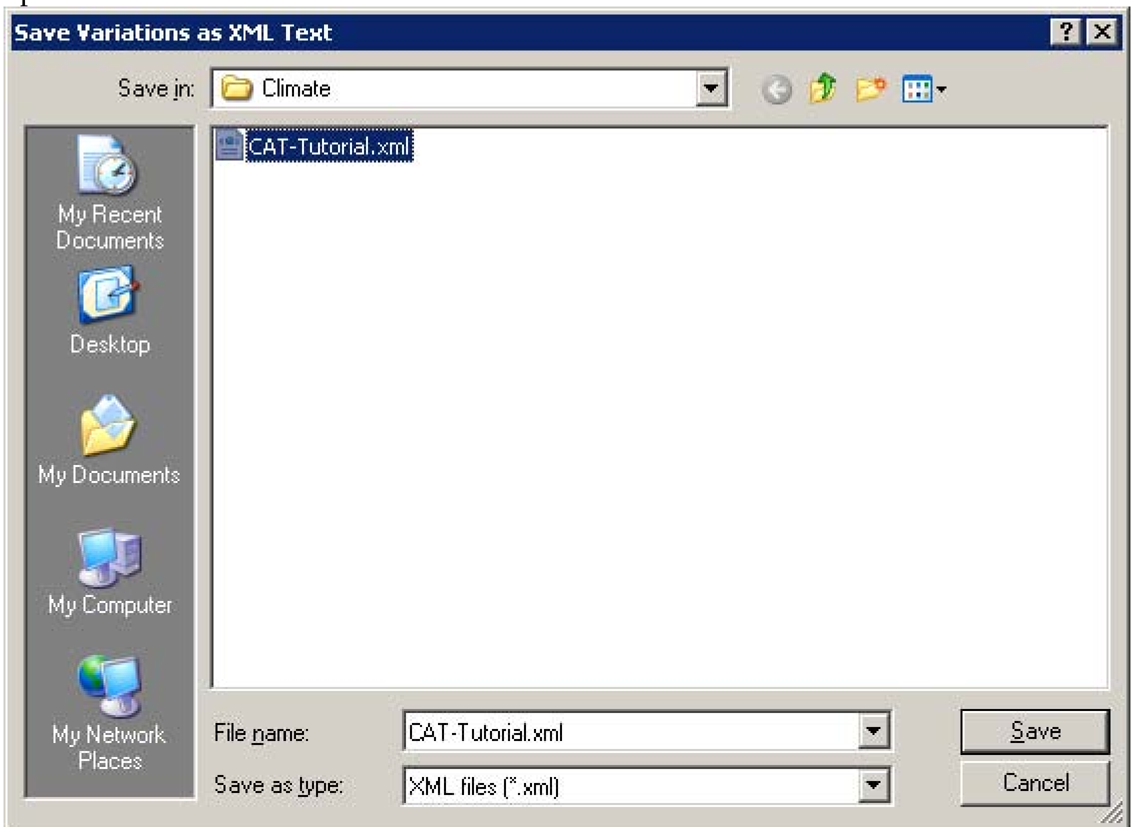
2. Before beginning the process of generating and analyzing climate change scenarios, a starting scenario must be specified upon which new scenarios will be based. To do this, click in the **Base Scenario** box and select the file \BASINS\data\Climate\base.uci. When this UCI file is selected, the input meteorological and output data files specified in the UCI file will be loaded into the BASINS project and made available for use in CAT.

Leave the **New Scenario** name as 'Modified'.



3. It is advisable to save the state of the Climate Assessment Tool as tutorial exercises are completed. This will allow later tutorials, which depend on results from earlier tutorials, to be run without re-running the earlier tutorials. To perform this save, select the **File:Save Climate and Endpoints** menu option. A file dialogue window will prompt you for the name of a file in which the state of CAT will be saved. This saved state may then be retrieved at a later time using the **File:Load Climate and Endpoints** menu

option.



4. At this point the generation and assessment of climate change scenarios may be performed. The remaining tutorial sections contain exercises showing how to generate new climate change scenarios, specify environmental endpoints, run an assessment, and summarize and visualize results.

3.1 Tools For Developing Climate Change Scenarios

BASINS CAT provides a flexible capability to modify historical meteorological time series to create climate change scenarios for use with the HSPF watershed model. As described in Chapter 2, a variety of modifications, or adjustments, may be applied to precipitation and temperature timeseries, along with a necessary capability to regenerate potential evapotranspiration (PET) when adjustments are made to air temperature.

The tutorials in this section illustrate the major types of adjustment that can be made to historical meteorological data to create climate change scenarios, including methods for modifying precipitation (3.1.1), modifying temperature/regenerating PET (3.1.2), and creating synthetic climate change scenarios (3.1.4). Within these sub-sections a number of tutorials demonstrate the specific methods by which these data may be modified.

3.1.1 Modify Historical Precipitation Records

The tutorials in this section demonstrate the following precipitation modifications:

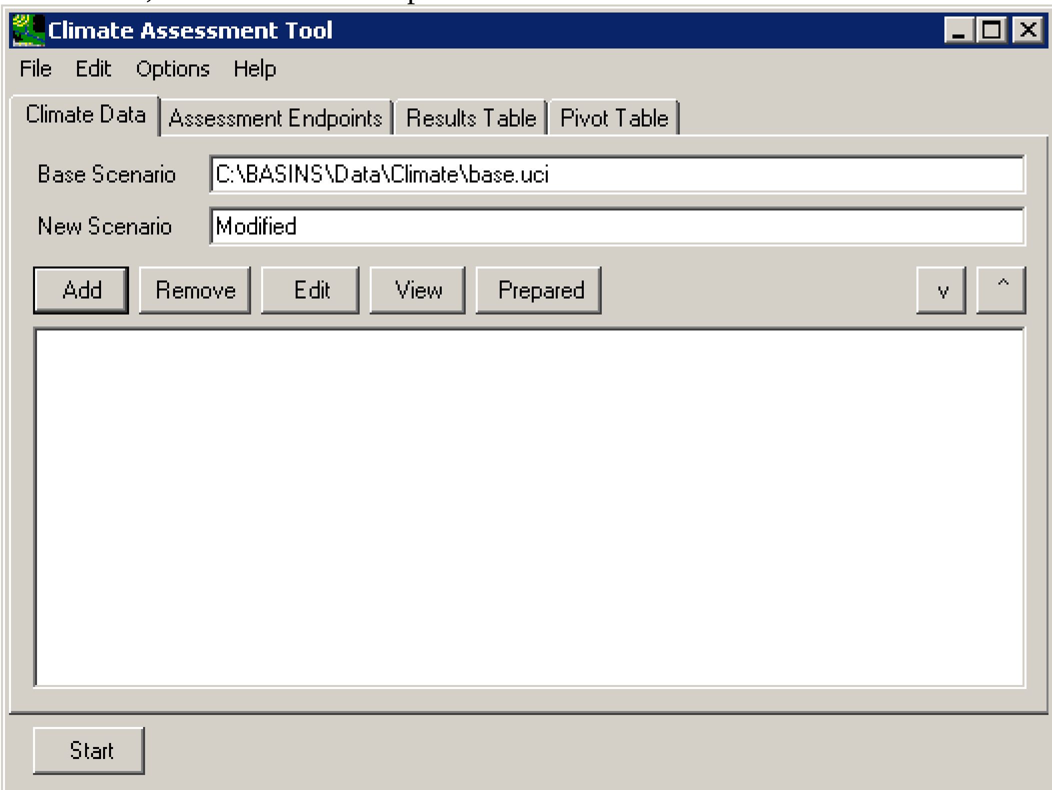
- Applying a multiplier to the entire record.
- Applying a seasonal multiplier.
- Applying a multiplier to a portion of the record.
- Representing Storm Intensification.
- Adding or Removing Storm Events.

These tutorials all assume that the BASINS-CAT Set-up tutorial, in Section 3.0, has already been run.

3.1.1.1 Apply Multiplier to Full Record

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file (not shown in the image below) added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in

Section 3.0, which must be run prior to this tutorial.

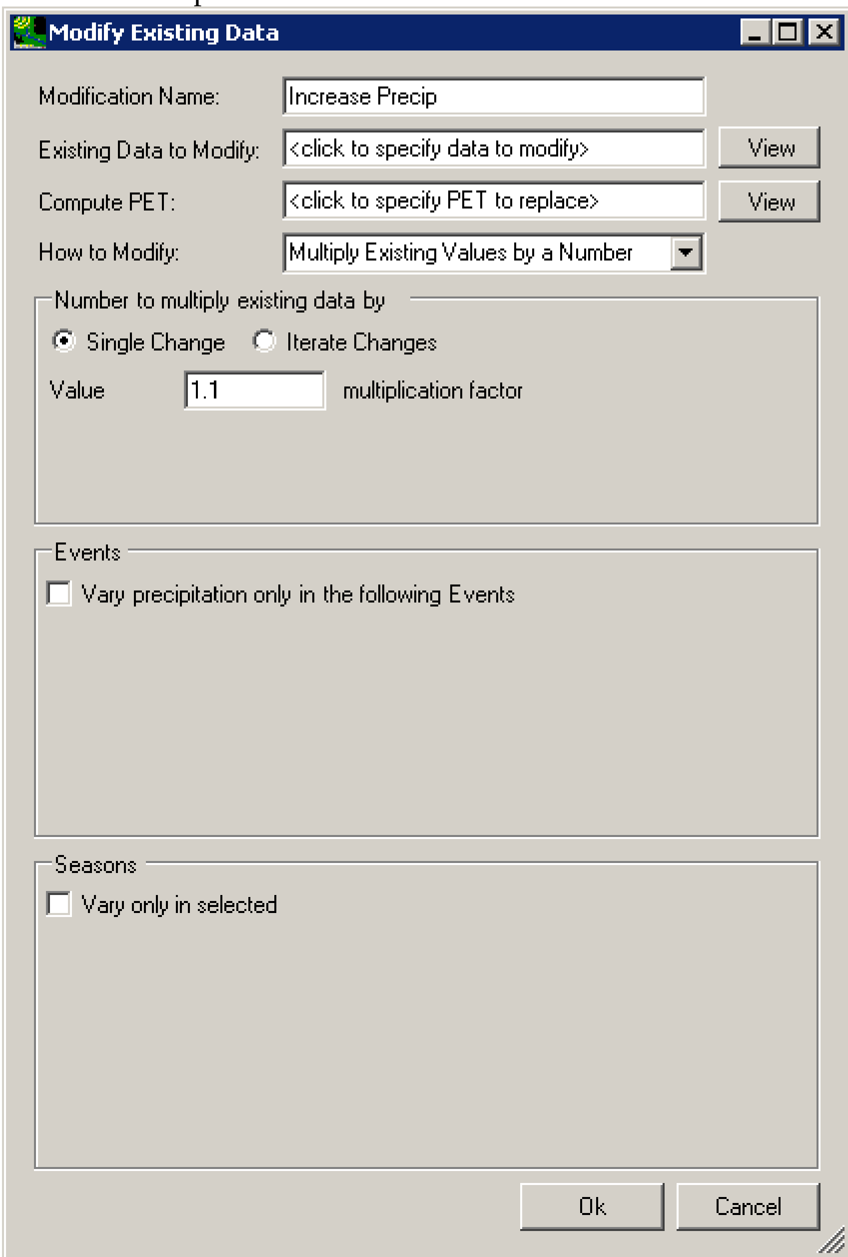


The simplest method of modifying precipitation is to apply a multiplier to historical values over the entire span of the model run. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.1.1.

This tutorial will show how a single multiplier may be applied to an entire historical precipitation data record. The final result of the tutorial will be a climate adjustment that applies a multiplier to historical precipitation data for use as model input.

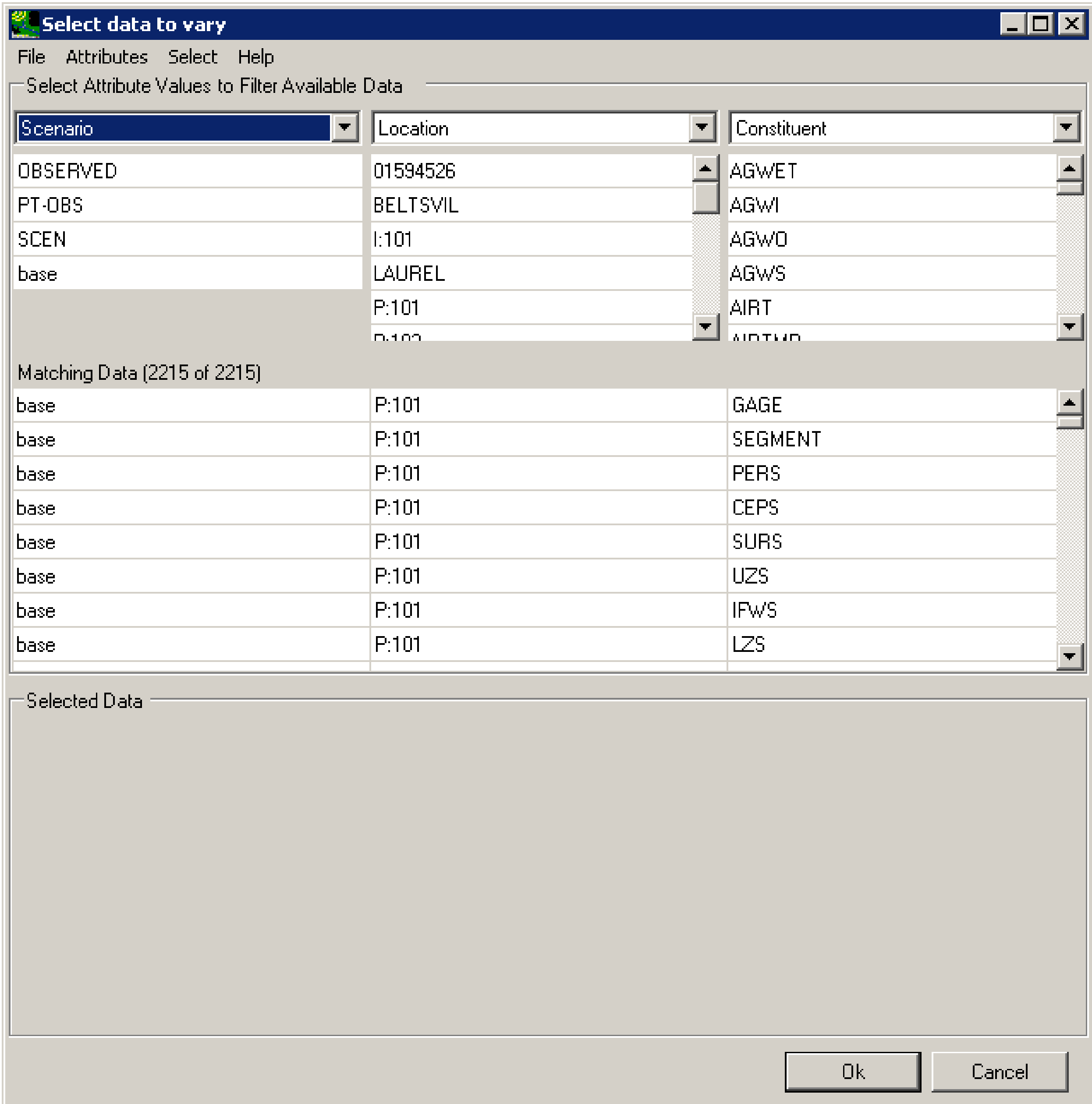
1. To begin creating a new climate adjustment, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this scenario by entering

'Increase Precip' in the **Modification Name** field.



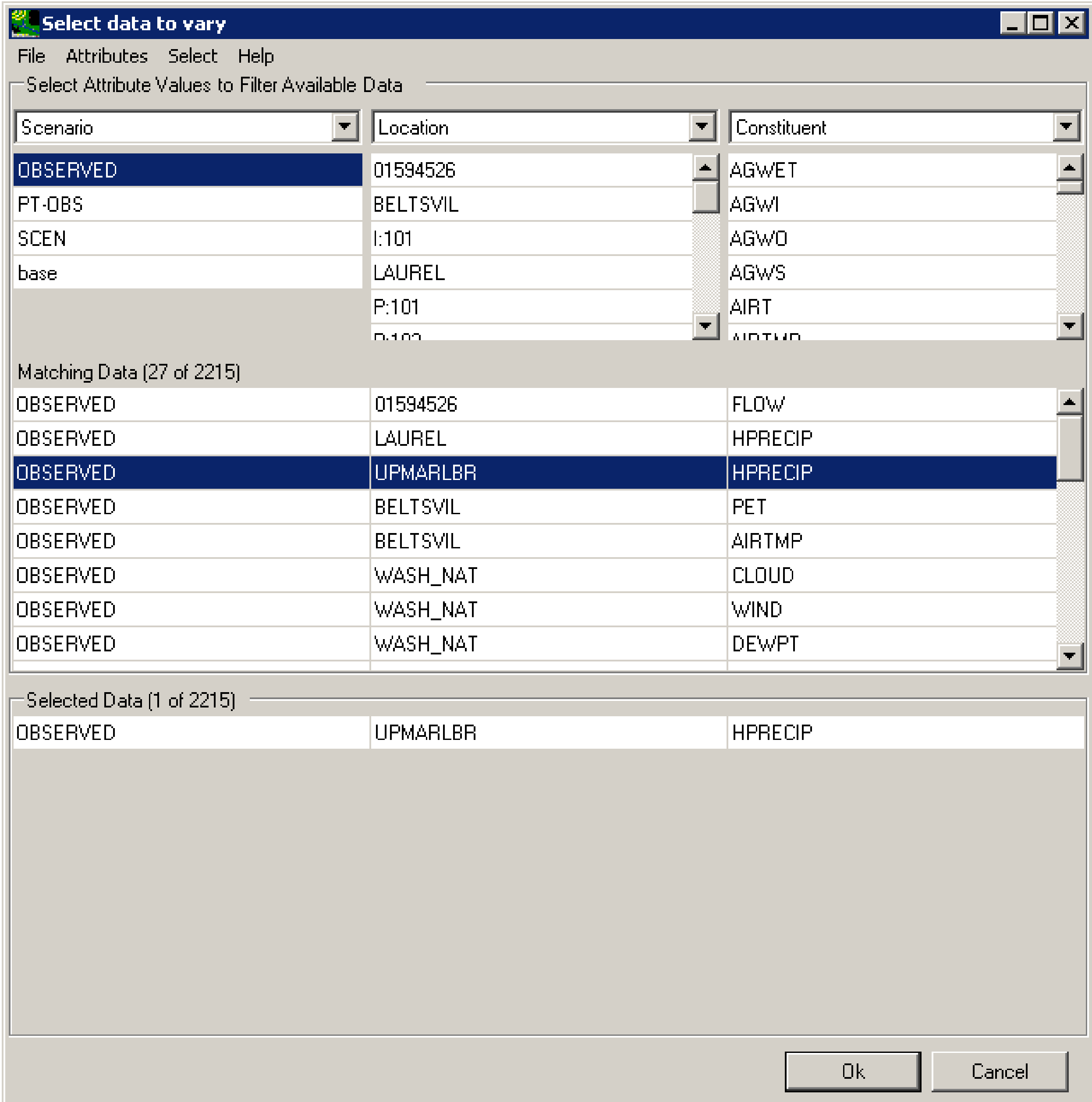
2. To select the precipitation data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. In the top third of this window, titled **Select Attribute Values to Filter Available Data**, you can filter the type of data to select by Scenario, Location, or Constituent. The data matching your selections will appear in the middle third of the window, titled **Matching Data**. To further filter the data, select one or more data sets from the **Matching Data** list, which will show up in the lower third of the window under **Selected Data**. If you would like to select all of the **Matching Data**, leave the **Selected Data** area blank. Click on individual data sets to

remove them from **Selected Data**.



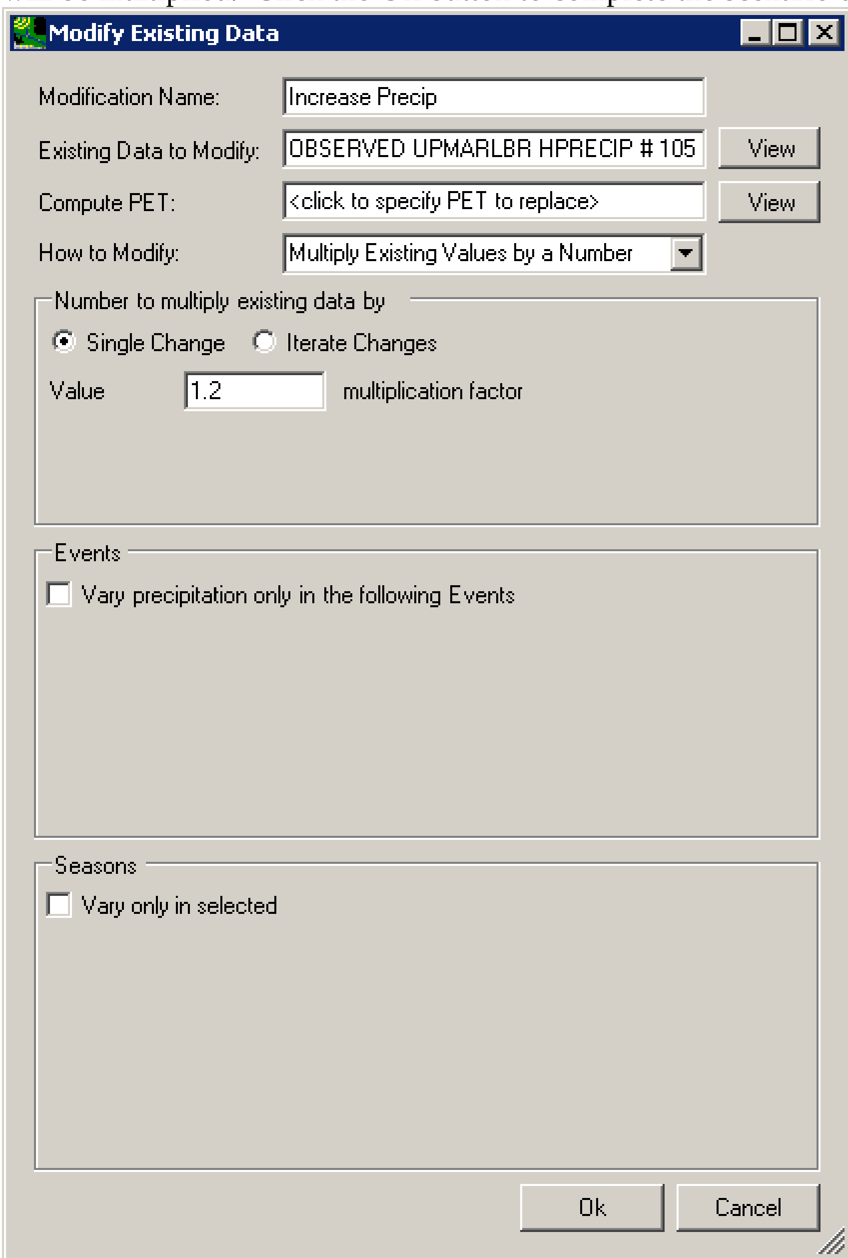
3. Begin the selection process by looking at the first column, labeled **Scenario**, in the **Select Attribute Values to Filter Available Data** frame. Click on the **OBSERVED** item and all data sets with a Scenario attribute of OBSERVED will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note that there are two data sets with the **Constituent** name **HPRECIP** (hourly precipitation). The HSPF model used in this example is only using precipitation from the Upper Marlboro gage, so click on the data set with **UPMARLBR** and **HPRECIP** as the respective **Location** and **Constituent**. (Note: It is possible for more than one data set to be selected for use in

defining a climate scenario.) When this data set has moved to the **Selected Data** list, click the **Ok** button.

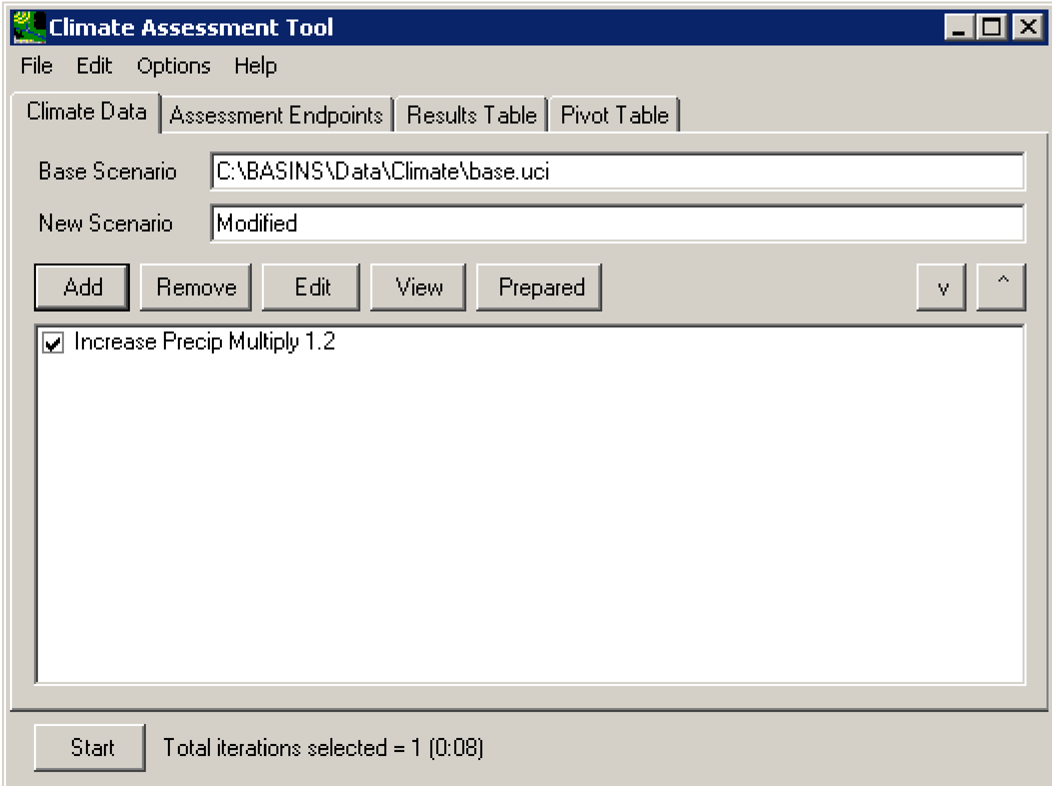


4. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. The **Compute PET** box is for selecting the evapotranspiration dataset to modify when a temperature climate scenario is being defined and may be ignored for this example. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, the "Modify Existing Values by a Number" option will be used. In the **Number to multiply existing data by** frame, there are two modification options: **Single Change** or **Iterate Changes**. The

term ‘iterate’ as used here refers to the automation of multiple runs. The **Single Change** option will result in one adjustment applied to the precipitation data set. The **Iterate Changes** option will result in a series of adjustments to the precipitation data set and is used to create “synthetic” climate change scenarios as described in Section 2.3.1.4. Use of this option is shown in the Tutorial found in Section 3.1.4 Create Synthetic Climate Change Scenarios. For this example, we will use the **Single Change** option. Enter ‘1.2’ in the **Value** field, thus defining the value by which all values in the precipitation data set will be multiplied. Click the **Ok** button to complete the scenario definition process.

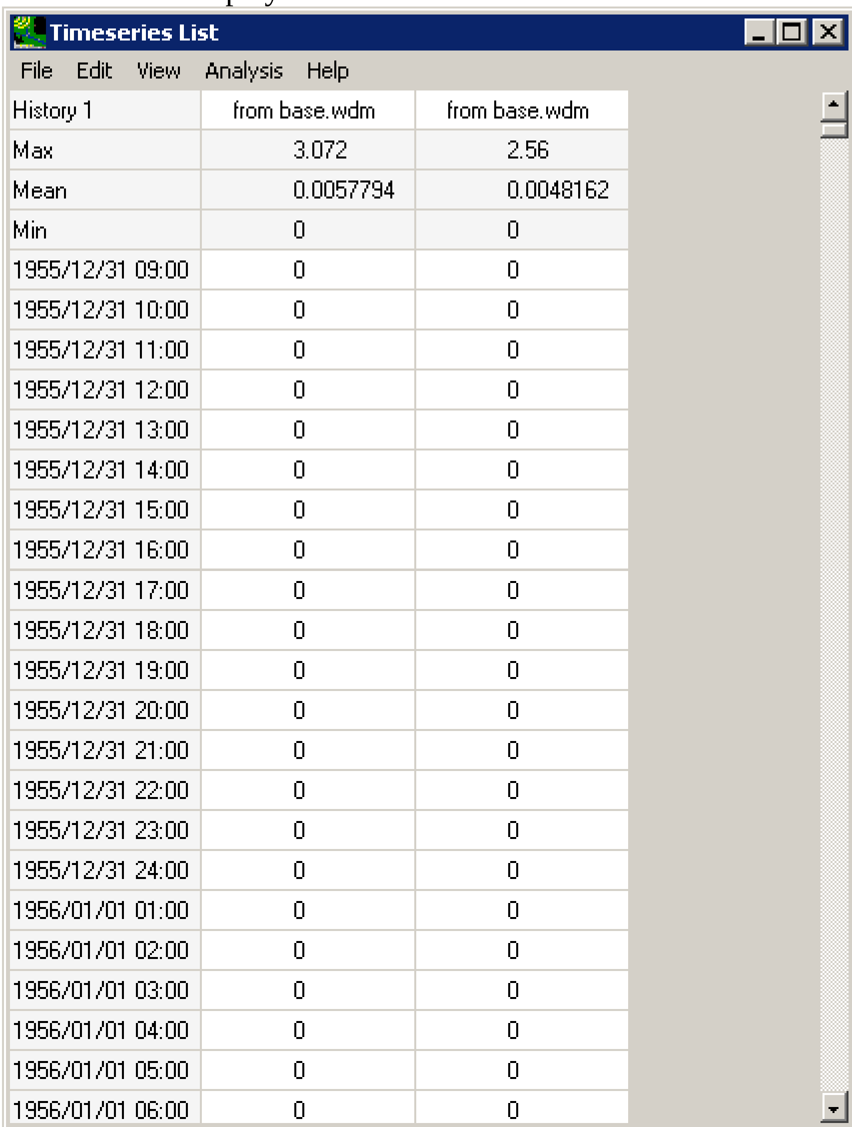


5. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario.



6. To view a listing of the modified precipitation data set, click on the newly created climate adjustment to highlight it and then click the **View** button. The **Time series List** window displays a listing of the values in the modified dataset. To view the modified data next to the original, select the **File:Select Data** menu option and the **Select Data** window will be displayed. Like earlier in this session, click the **OBSERVED** item from the **Scenario** list and then click the **OBSERVED, UPMARLBR, HPRECIP** data set from the **Matching Data** list. It will be added to the **Selected Data** list along with the modified precipitation data set that is already in the **Time series List** window. Click **Ok** and the two data sets'

values will be displayed.



Timeseries List

File Edit View Analysis Help

History 1	from base.wdm	from base.wdm
Max	3.072	2.56
Mean	0.0057794	0.0048162
Min	0	0
1955/12/31 09:00	0	0
1955/12/31 10:00	0	0
1955/12/31 11:00	0	0
1955/12/31 12:00	0	0
1955/12/31 13:00	0	0
1955/12/31 14:00	0	0
1955/12/31 15:00	0	0
1955/12/31 16:00	0	0
1955/12/31 17:00	0	0
1955/12/31 18:00	0	0
1955/12/31 19:00	0	0
1955/12/31 20:00	0	0
1955/12/31 21:00	0	0
1955/12/31 22:00	0	0
1955/12/31 23:00	0	0
1955/12/31 24:00	0	0
1956/01/01 01:00	0	0
1956/01/01 02:00	0	0
1956/01/01 03:00	0	0
1956/01/01 04:00	0	0
1956/01/01 05:00	0	0
1956/01/01 06:00	0	0

7. To complete this session, close the data listing and save the state of CAT, using the **File:Save Climate and Endpoints** menu option, if desired.

3.1.1.2 Apply Seasonal Multiplier

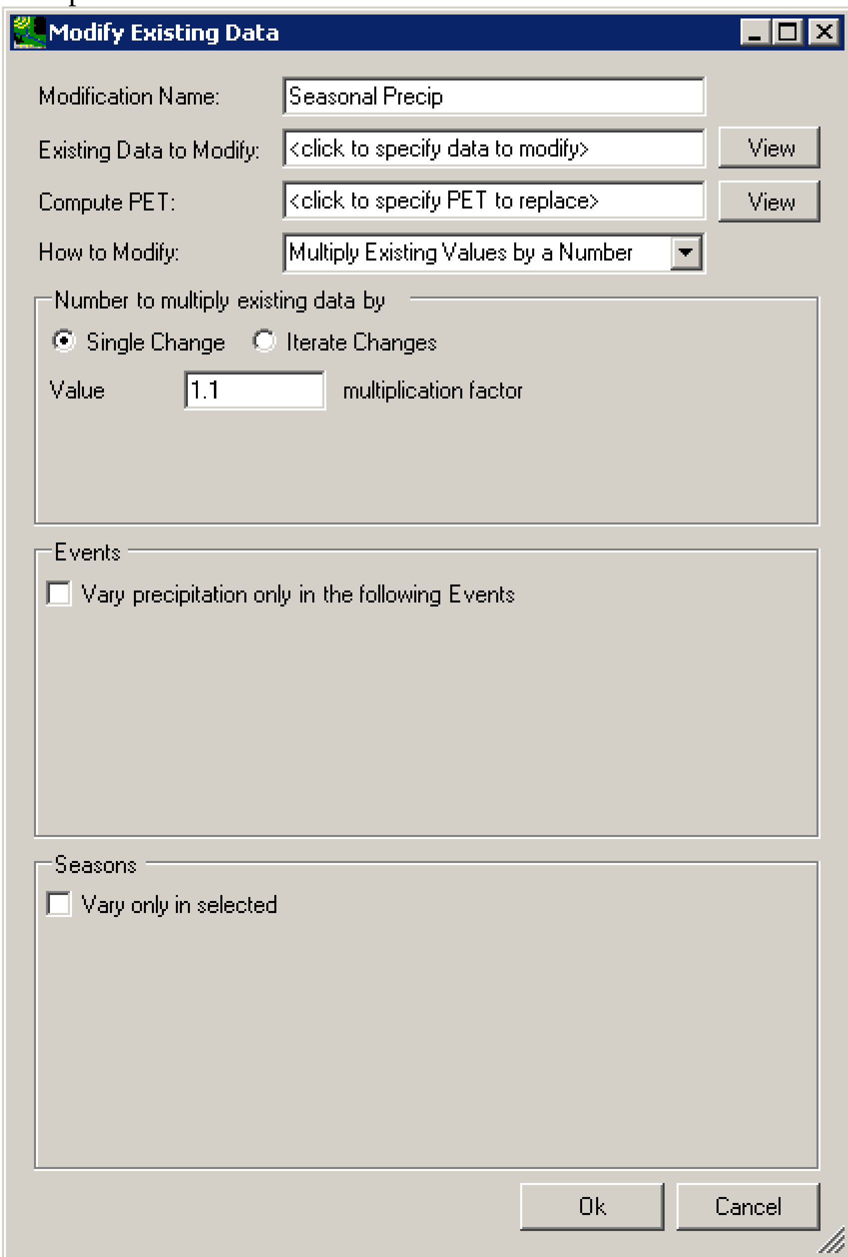
To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the “\Basins\Data\Climate\base.uci” file as the **Base Scenario**, “Modified” as the **New Scenario**, and the “\Basins\Data\Climate\base.wdm” file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

A common climate scenario need is to adjust historical values during a particular portion of the year over the entire span of the model run. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.1.2.

This tutorial will show how a single multiplier may be applied to precipitation data during a specific portion of the year. The final result of the tutorial will be a climate scenario that applies a multiplier to historical precipitation data during summer months for use as model input.

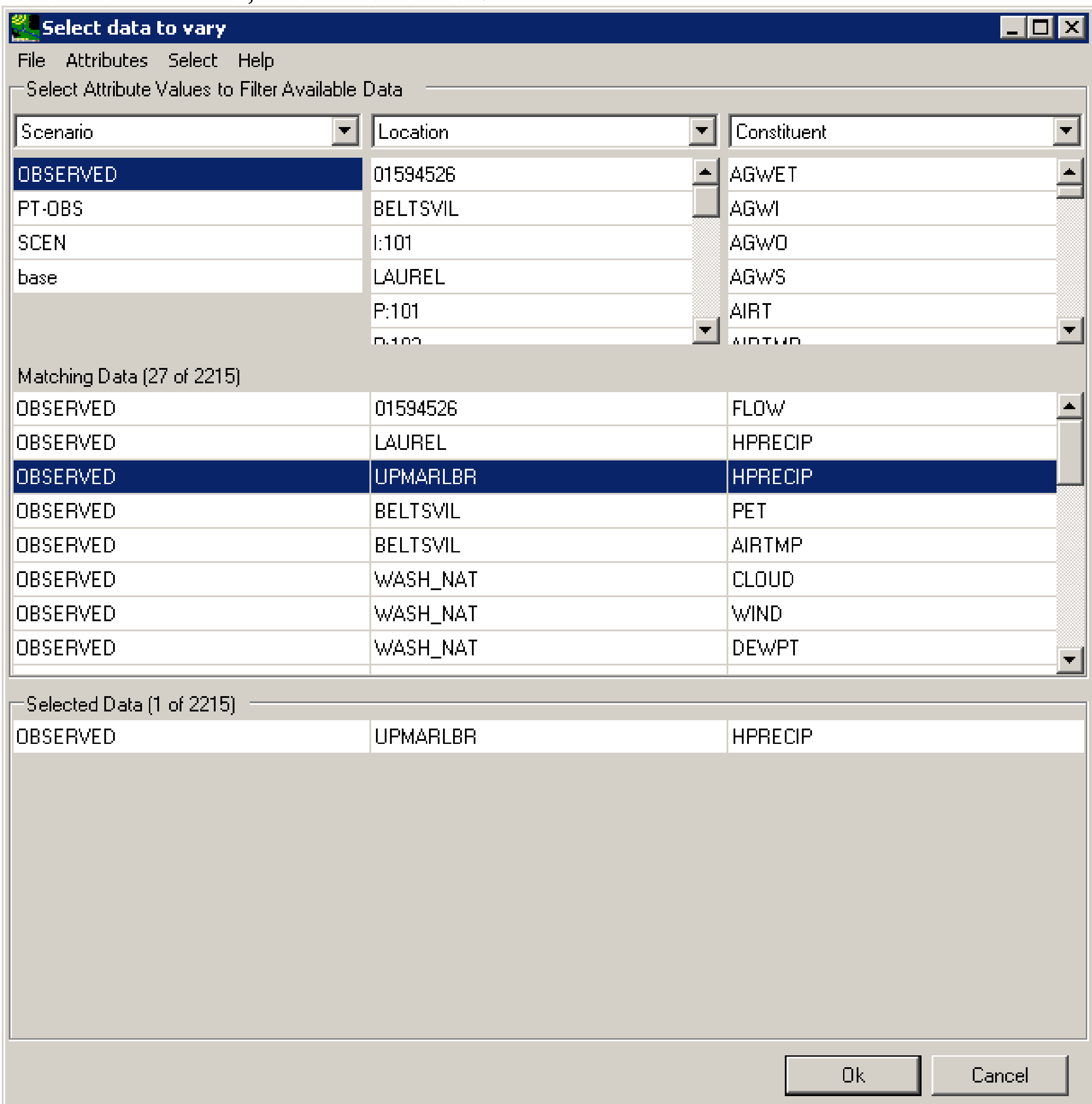
1. To begin creating a new climate scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this scenario by entering ‘Seasonal

Precip' in the **Modification Name** field.



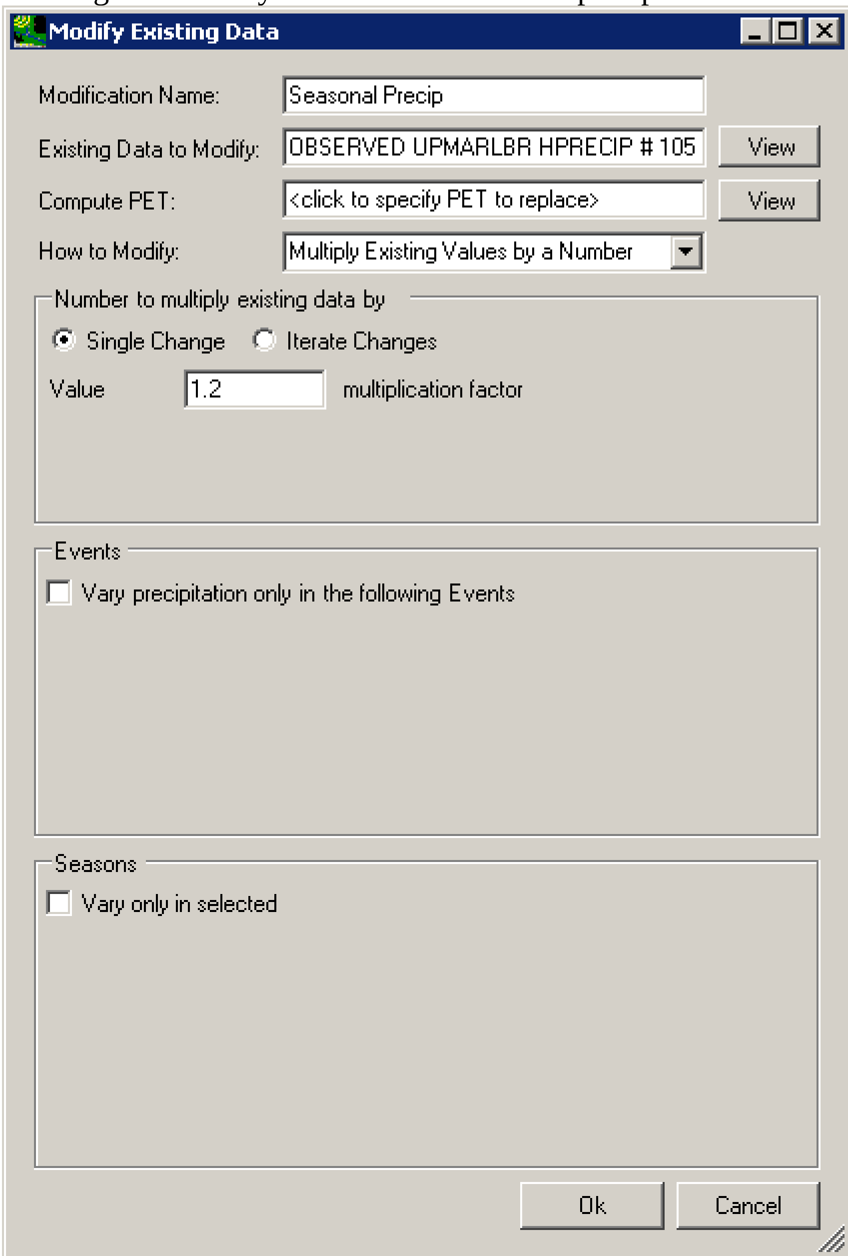
2. To select the precipitation data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.1.1. In the first column, under the **Scenario** label, click on the **OBSERVED** item. In looking at the **Matching Data** list, note that there are two data sets with the **Constituent** name **HPRECIP** (hourly precipitation). The HSPF model used in this example is only applying precipitation from the Upper Marlboro gage, so click on the data set with **UPMARLBR** and **HPRECIP** as the respective **Location** and **Constituent**. (Note: It is possible for more than one data set

to be selected for use in defining a climate scenario.) When this data set has moved to the **Selected Data** list, click the **Ok** button.



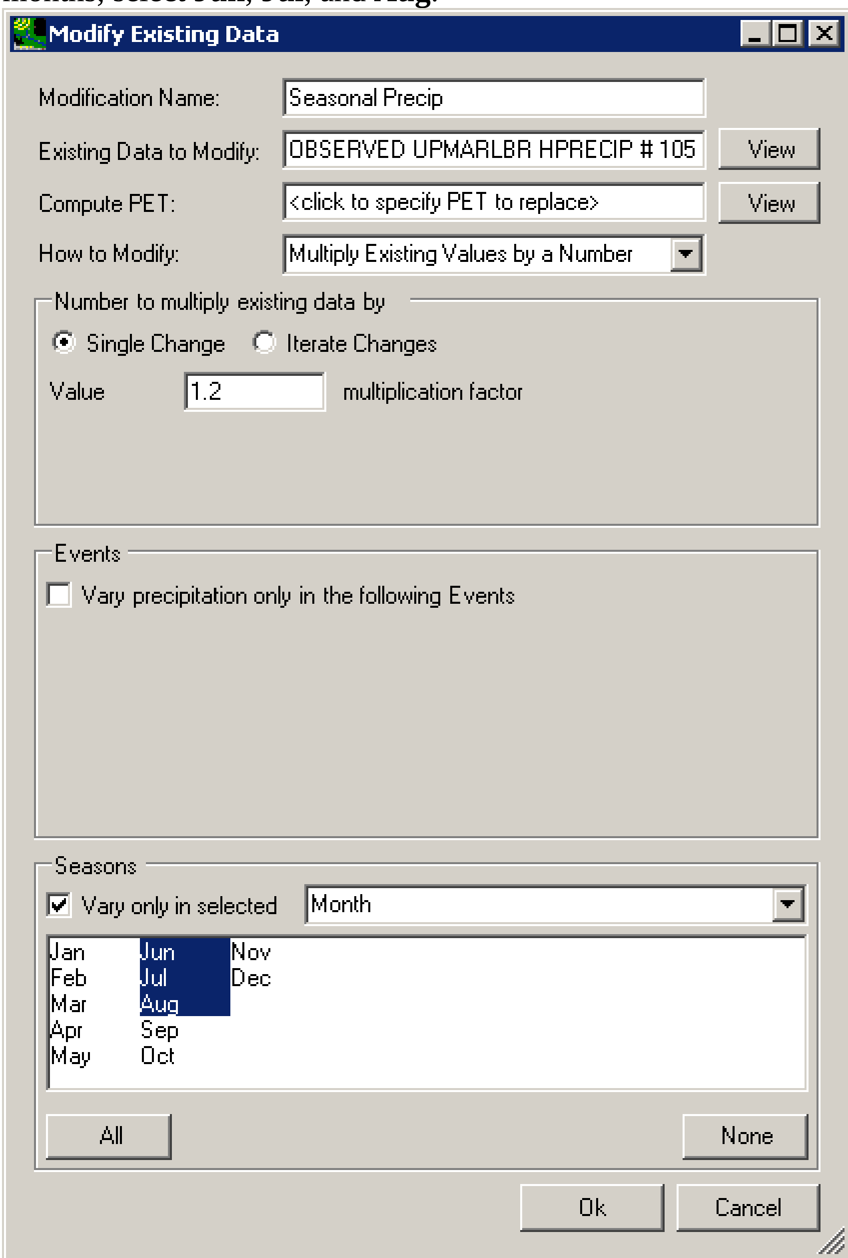
3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. The **Compute PET** box is for selecting the evapotranspiration dataset to modify when a temperature climate scenario is being defined and may be ignored for this example. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, the "Modify Existing Values by a Number" option will be used. A detailed description of the **Number to multiply existing data by** frame is found in the tutorial in Section 3.1.1.1. For this

example, we will use the **Single Change** option. Enter '1.2' in the **Value** field, thus defining the value by which all values in the precipitation data set will be multiplied.

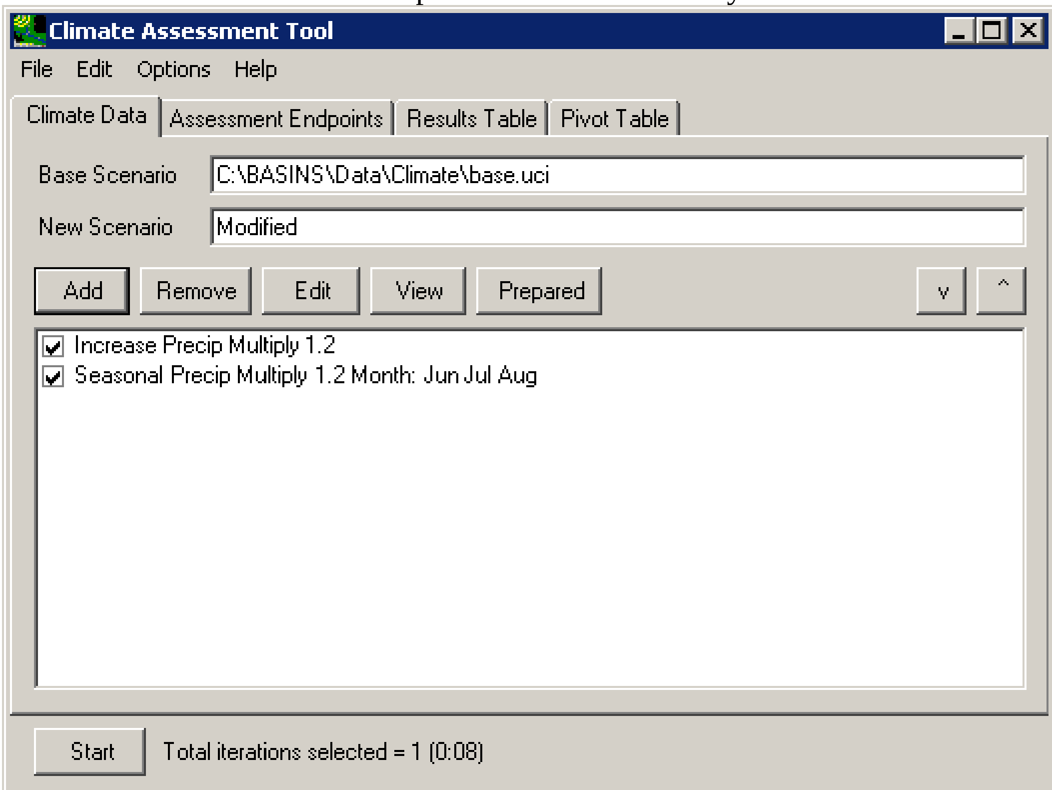


4. The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. Begin defining this subset by clicking on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of

record of the data set. For this example, select the **Months** option and the second field will be populated with the months of the year. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. To represent increased precipitation during summer months, select **Jun**, **Jul**, and **Aug**.



5. Click the **Ok** button to complete the scenario definition process. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario.



6. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

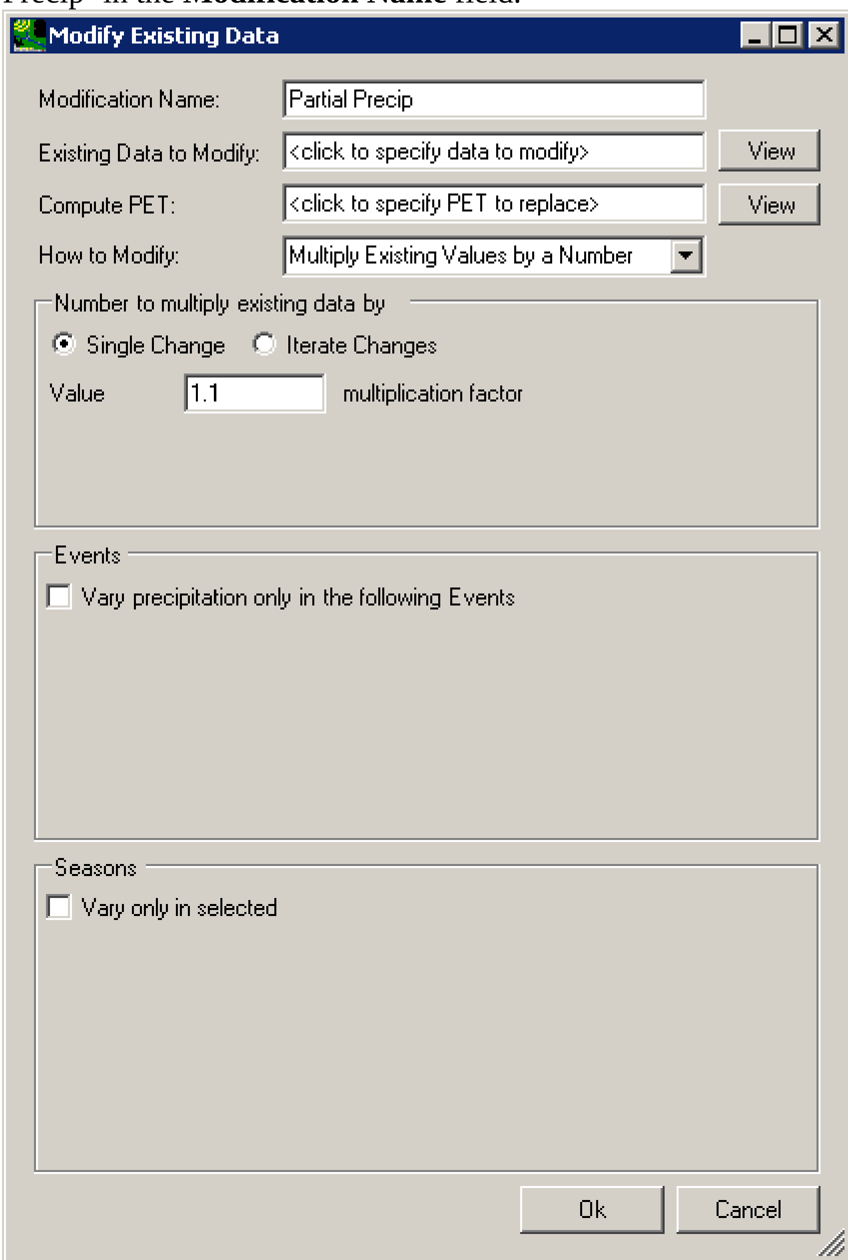
3.1.1.3 Modify Partial Record

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

A common climate scenario need is to adjust historical values during a particular portion of the model run. For example, investigating the impacts of drought may include decreasing the precipitation total for an already low-rainfall year. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.1.3.

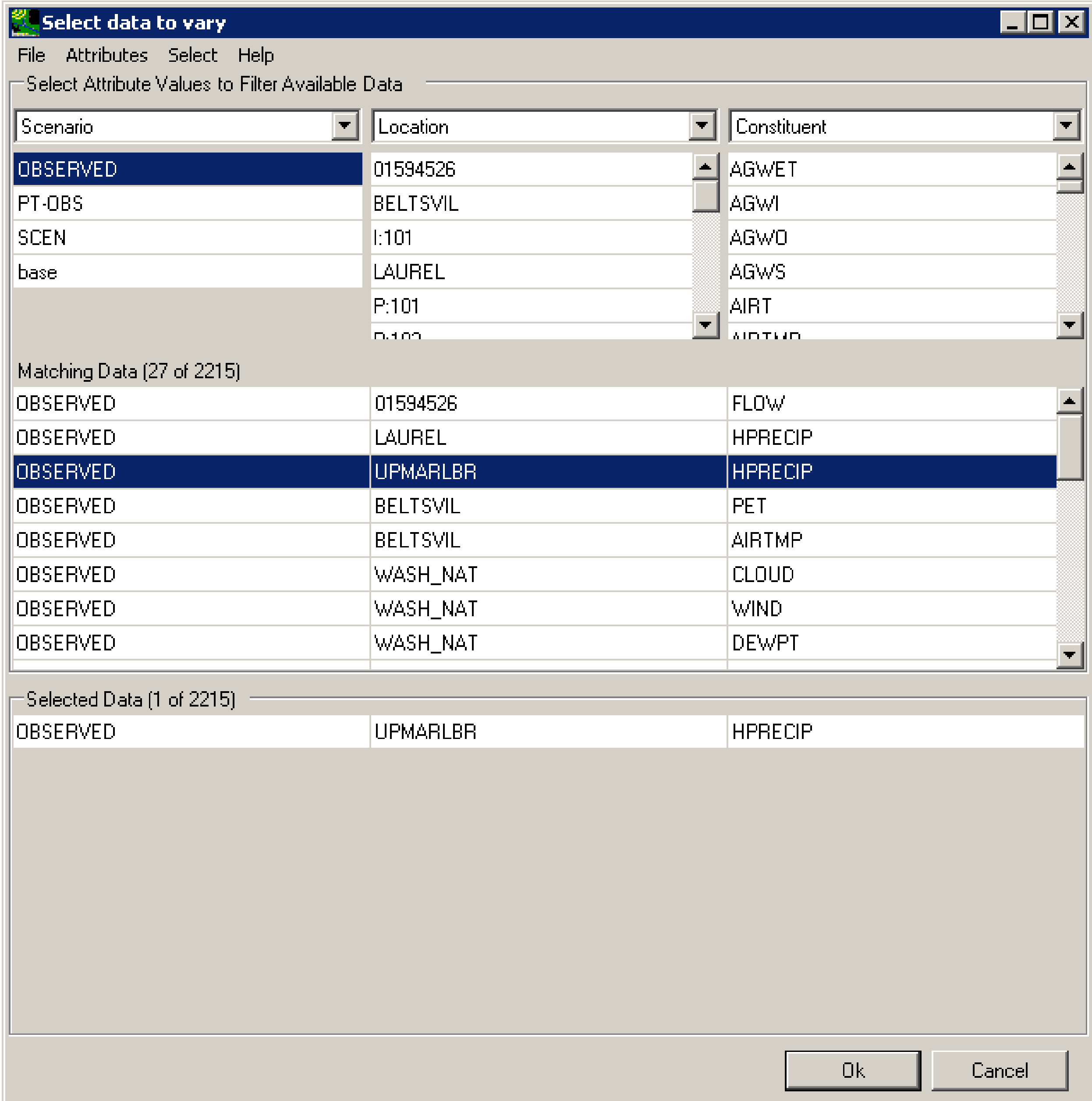
This tutorial will show how a single multiplier may be applied to precipitation data during a specific portion of the model run. The final result of the tutorial will be a climate adjustment that applies a multiplier to historical precipitation data during one year of a model run.

1. To begin creating a new climate scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this scenario by entering 'Partial Precip' in the **Modification Name** field.



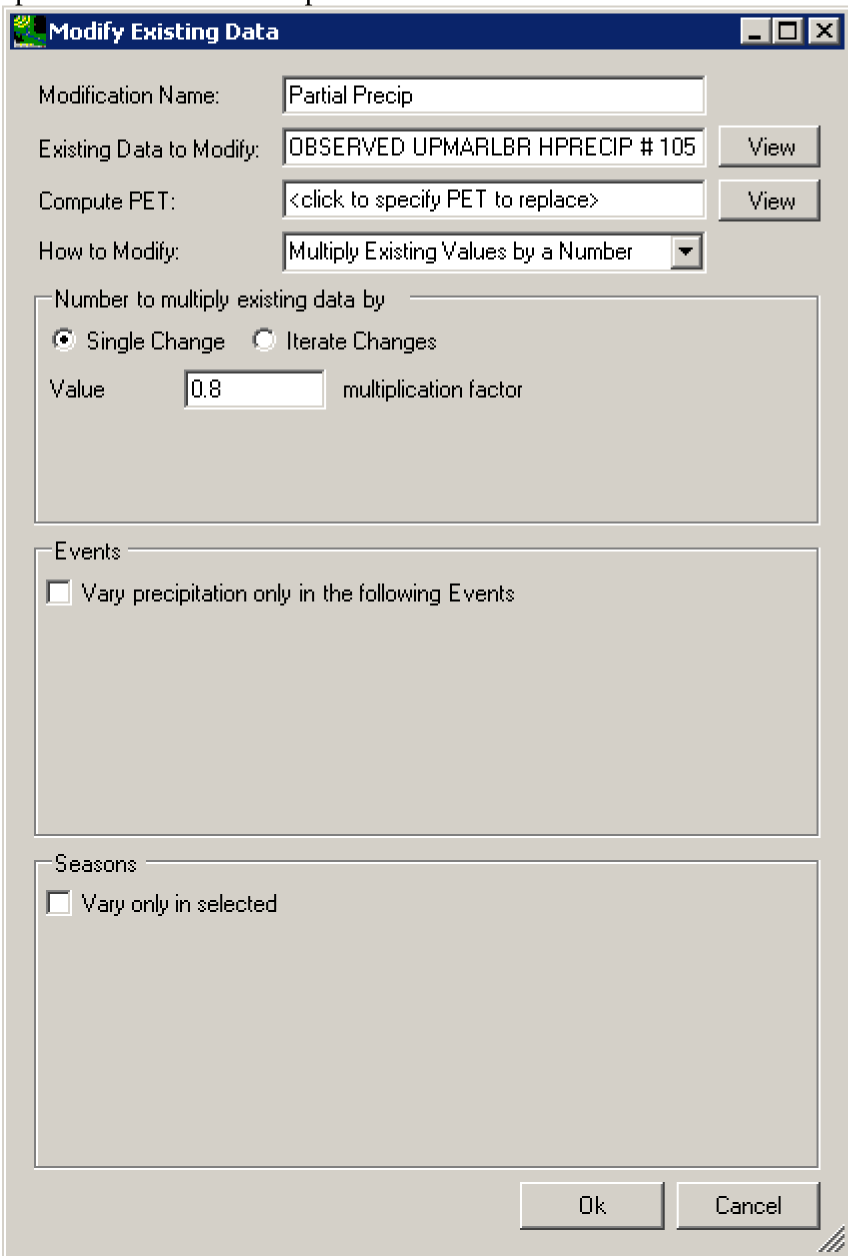
2. To select the precipitation data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.1.1. In the first column, under the **Scenario** label, click on the **OBSERVED** item . In looking at the **Matching Data** list, note that there are two data sets with the **Constituent** name **HPRECIP** (hourly precipitation). The HSPF model used in this example is only applying precipitation from the Upper Marlboro gage, so click on the data set with **UPMARLBR** and **HPRECIP** as the respective **Location** and **Constituent**. (Note: It is possible for more than one data set to be selected for use in defining a climate scenario.) When this data set has moved to

the **Selected Data** list, click the **Ok** button.



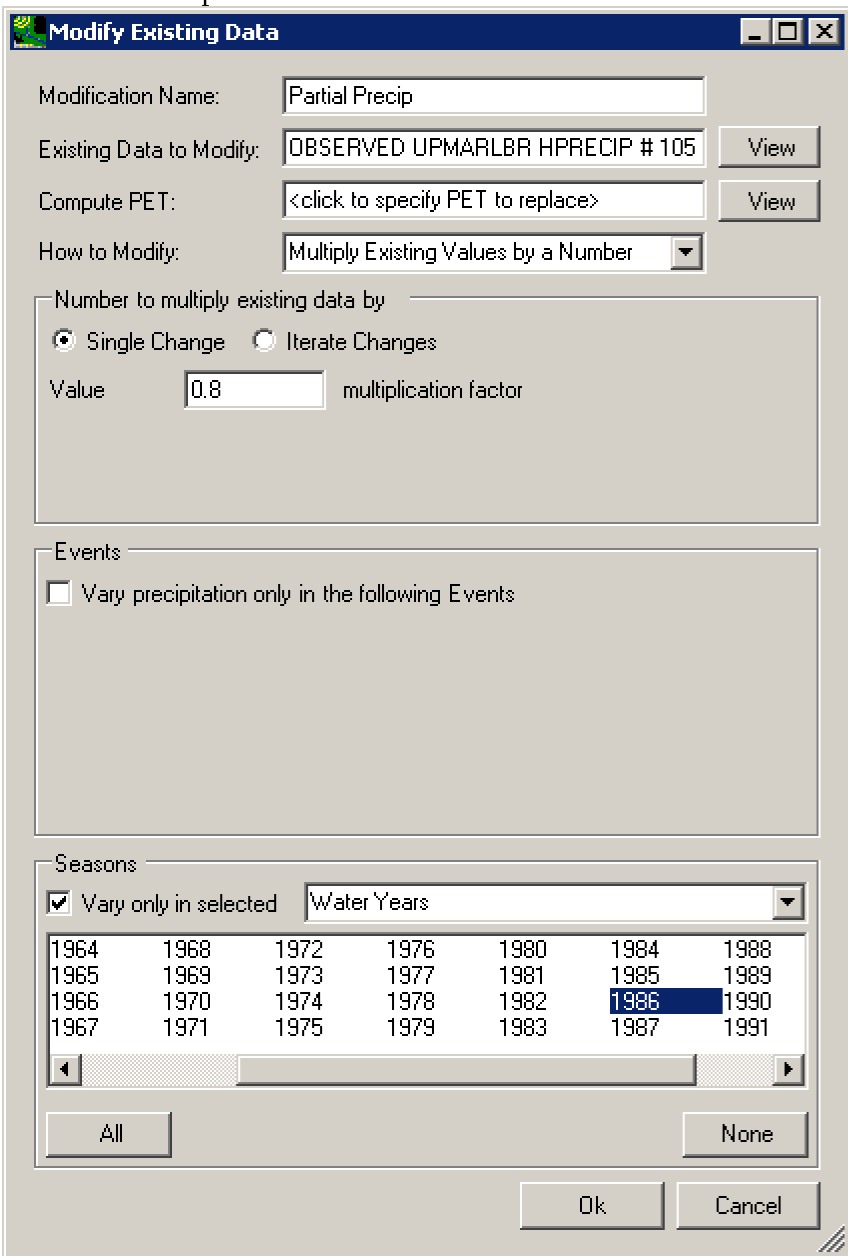
3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. The **Compute PET** box is for selecting the evapotranspiration dataset to modify when a temperature climate scenario is being defined and may be ignored for this example. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, the "Modify Existing Values by a Number" option will be used. A detailed description of the **Number to multiply existing data by** frame is found in the tutorial in Section 3.1.1.1. For this example, we will use the **Single Change** option. Enter '0.8' in the **Value** field, thus

defining the value by which the precipitation values will be multiplied during the year specified in the next step.

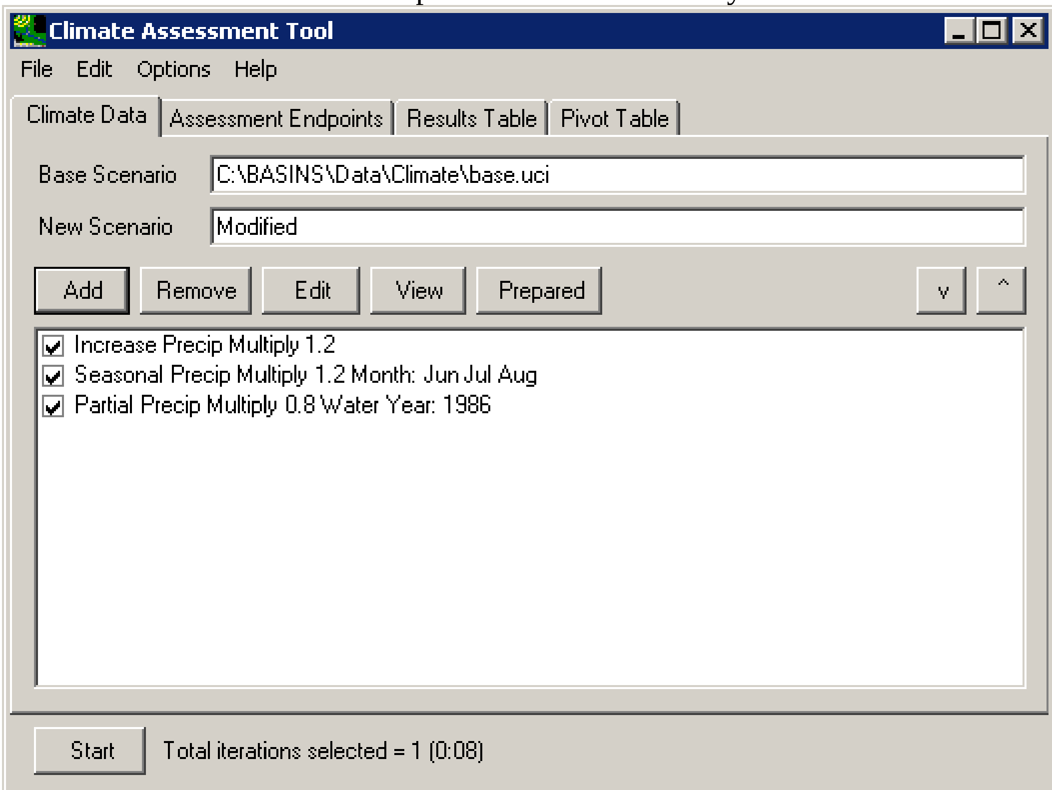


4. The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. Begin defining this subset by clicking on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of

record of the data set. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. The sample HSPF run used here is run for water years 1986 through 1988, with 1986 being the driest. Thus, to help assess the impact of drought, select the **Water Years** option and then select **1986** from the list of available water years.



5. Click the **Ok** button to complete the scenario definition process. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario.



6. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

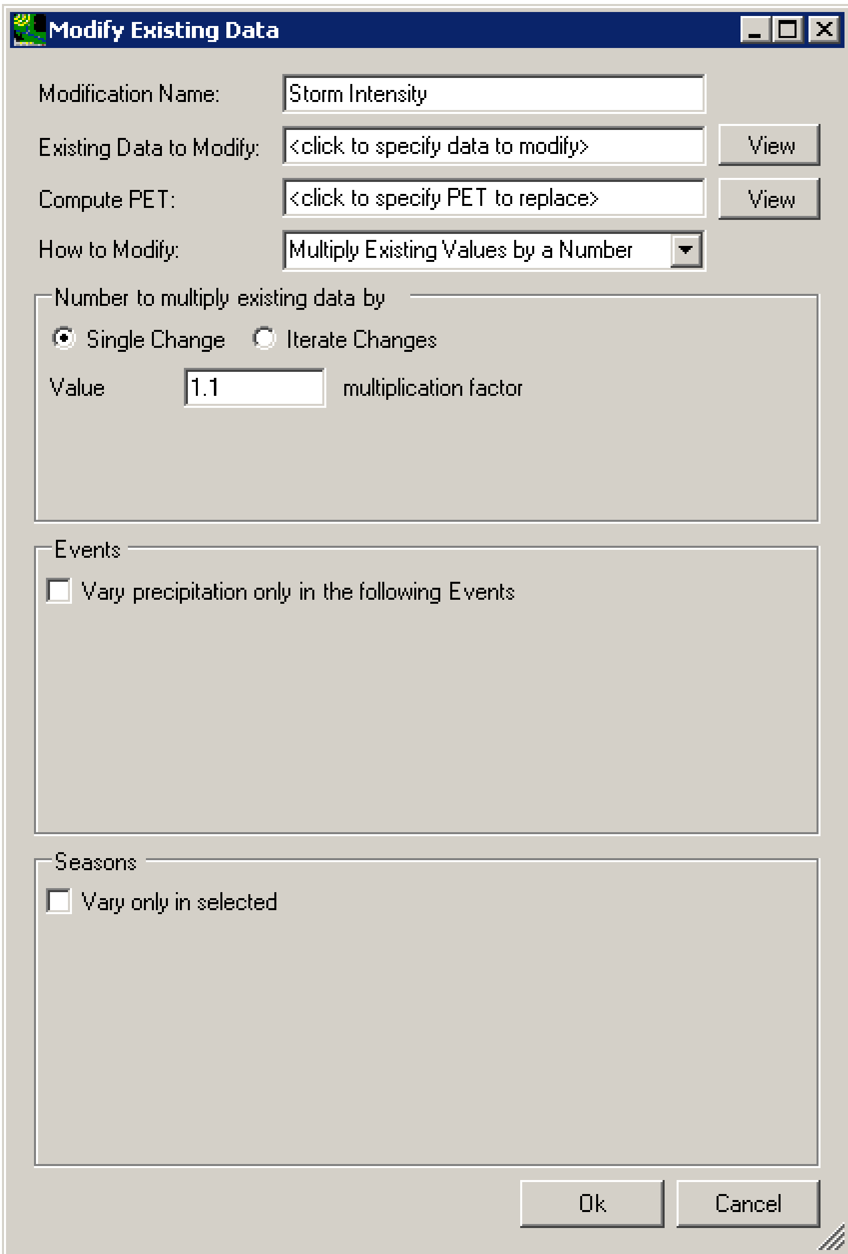
3.1.1.4 Represent Storm Intensification

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the “\Basins\Data\Climate\base.uci” file as the **Base Scenario**, “Modified” as the **New Scenario**, and the “\Basins\Data\Climate\base.wdm” file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

CAT has the ability to represent storm intensification by increasing storm volumes by a specified percent for a selected portion of the highest percentage storms. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.1.4.

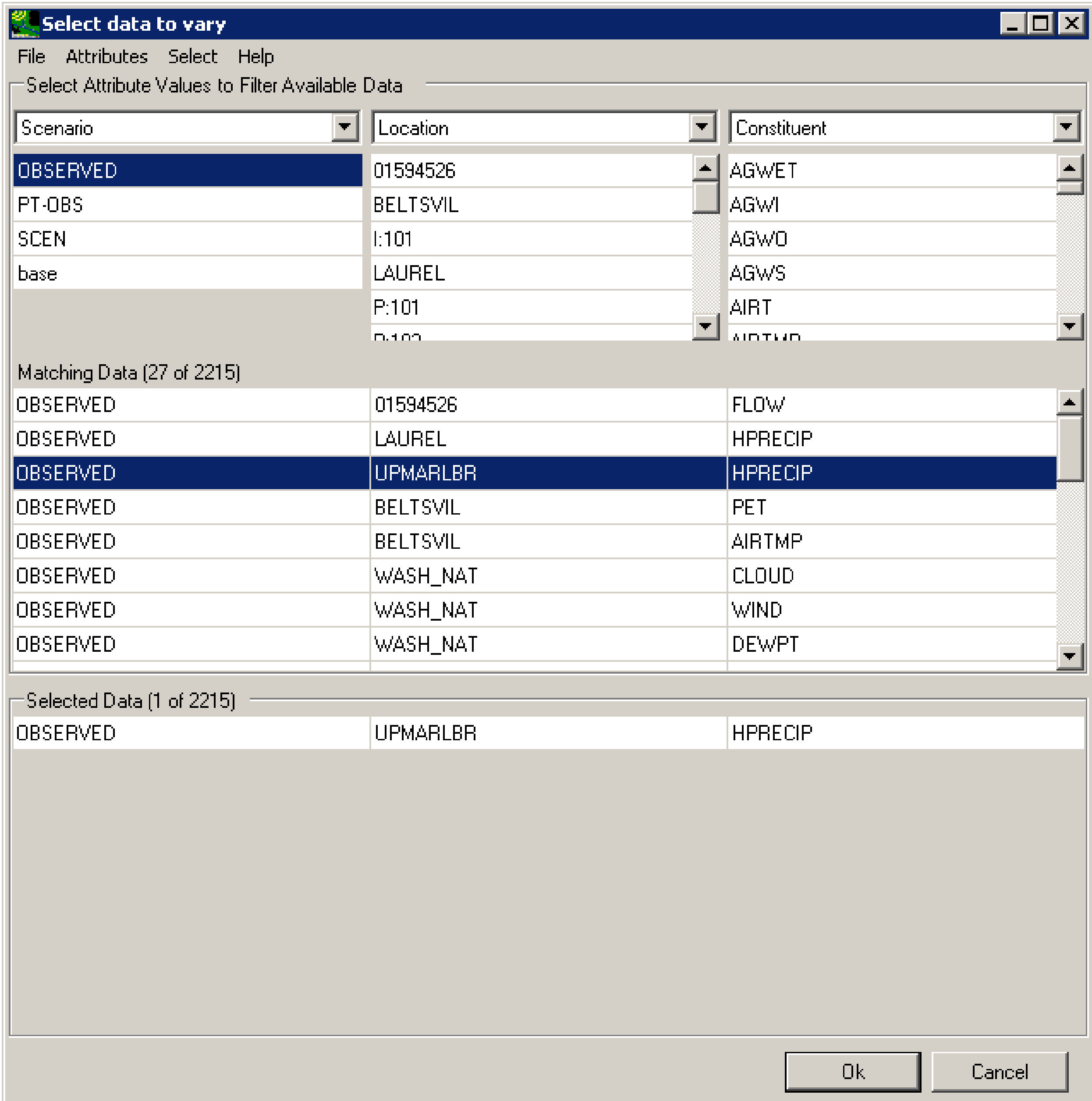
This tutorial will show how to make specifications to represent storm intensification. The final result of the tutorial will be a climate scenario that applies an increase to storm volumes in a specified percentage of storm events.

1. To begin creating a new climate scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. Begin defining this scenario by entering 'Storm Intensity' in the **Modification Name** field.



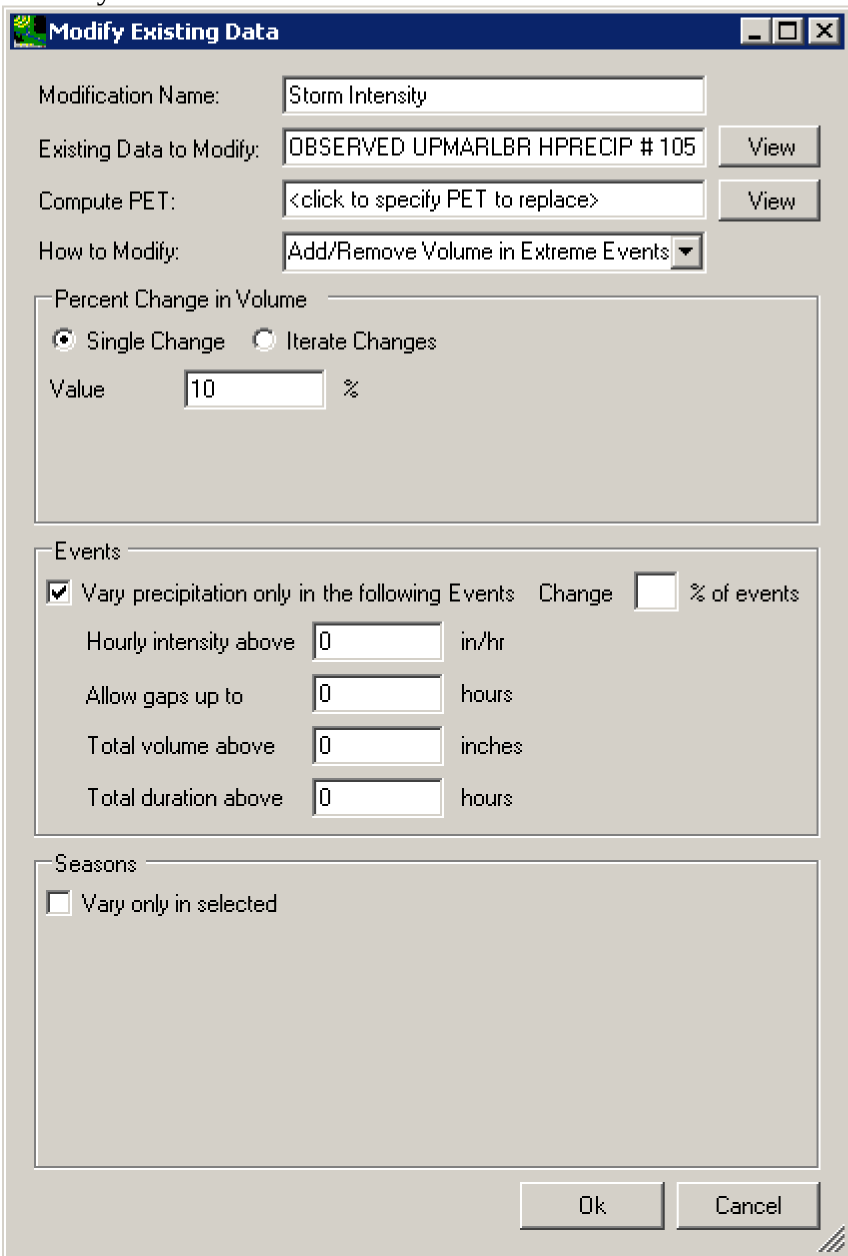
2. Since we will be modifying historical precipitation data, begin the selection process by clicking on the **OBSERVED** item under the **Scenario** list. In looking at the **Matching Data** list, note that there are two data sets with the **Constituent** name **HPRECIP** (hourly precipitation). The HSPF model used in this example is only applying precipitation from

the Upper Marlboro gage, so click on the data set with **UPMARLBR** and **HPRECIP** as the respective **Location** and **Constituent**. (Note: It is possible for more than one data set to be selected for use in defining a climate scenario.) When this data set has moved to the **Selected Data** list, click the **Ok** button.



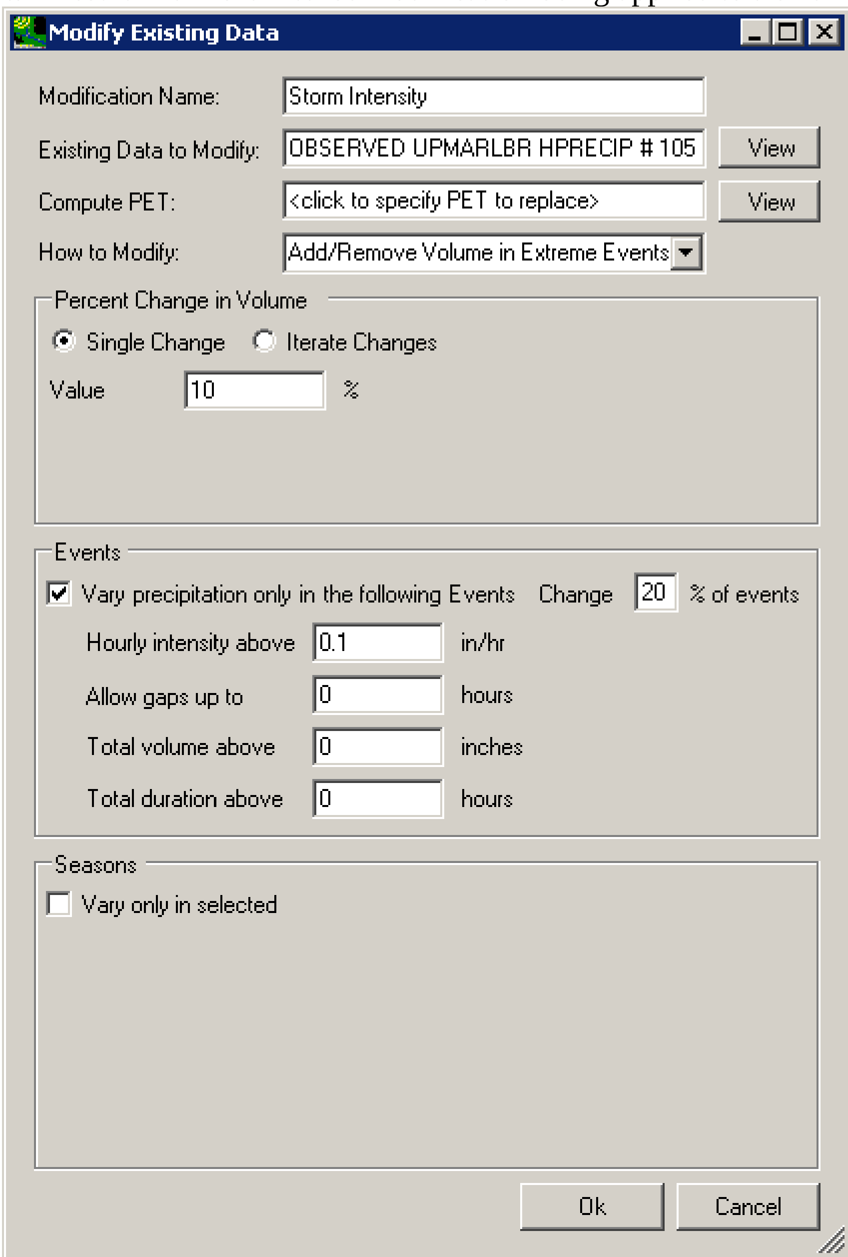
3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. The **Compute PET** box is for selecting the evapotranspiration dataset to modify when a temperature climate scenario is being defined and may be ignored for this example. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, select 'Add/Remove

Volume in Extreme Events'. The form will be updated to allow for specification of storm intensity modifications.



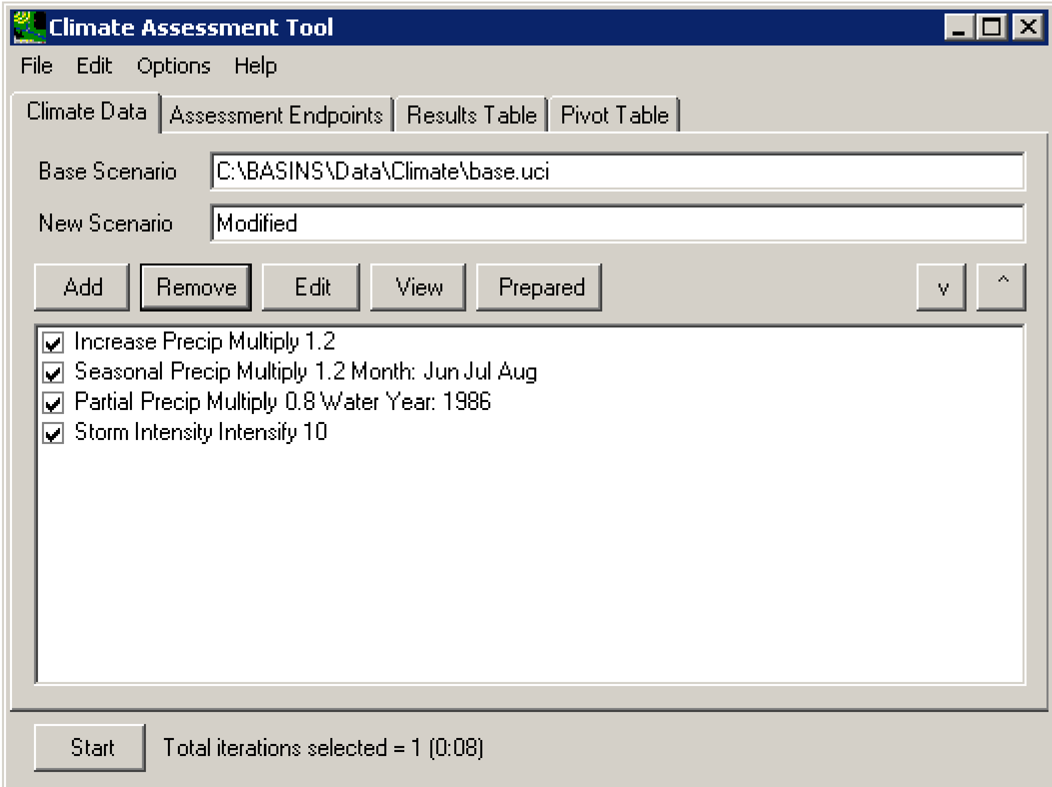
4. In the **Percent Change in Volume** frame leave the **Single Change** option selected and enter a value of '10' percent. It is important to note that this value indicates the percent change in the total water volume for the entire data set. In the **Events** frame, there are two components available for specifying storm intensification: **Vary precipitation only in the following Events** and **Change** a specified **% of events**. By default the option to **Vary precipitation only in the following Events** is checked. Values may be entered for any or all of the four elements that define an extreme event. Enter '0.1' in the **Total**

volume above field, indicating that only events with greater than 0.1 inches/hour will be considered storm events. The **Change ... % of events** field is used to specify the percentage of the qualifying events to be modified. Leaving this field blank will result in the specified volume change being applied to all qualifying events. Entering a percentage value will result in the volume change being applied to the highest storms that total that percentage of the data set's volume. Enter a value of '20' percent of the events, which will result in a more intense modification being applied to a smaller subset of storms.



5. Click the **Ok** button at the bottom of the window. This scenario, as summarized on the main CAT form, will **intensify** the storms defined on the previous form by adding 10%

of the data set's total volume to them.



6. Having completed defining this scenario, you may use the **View** button to see the values in the modified data sets. You may also want to save the state of CAT using the **File:Save Climate and Endpoints** menu option.

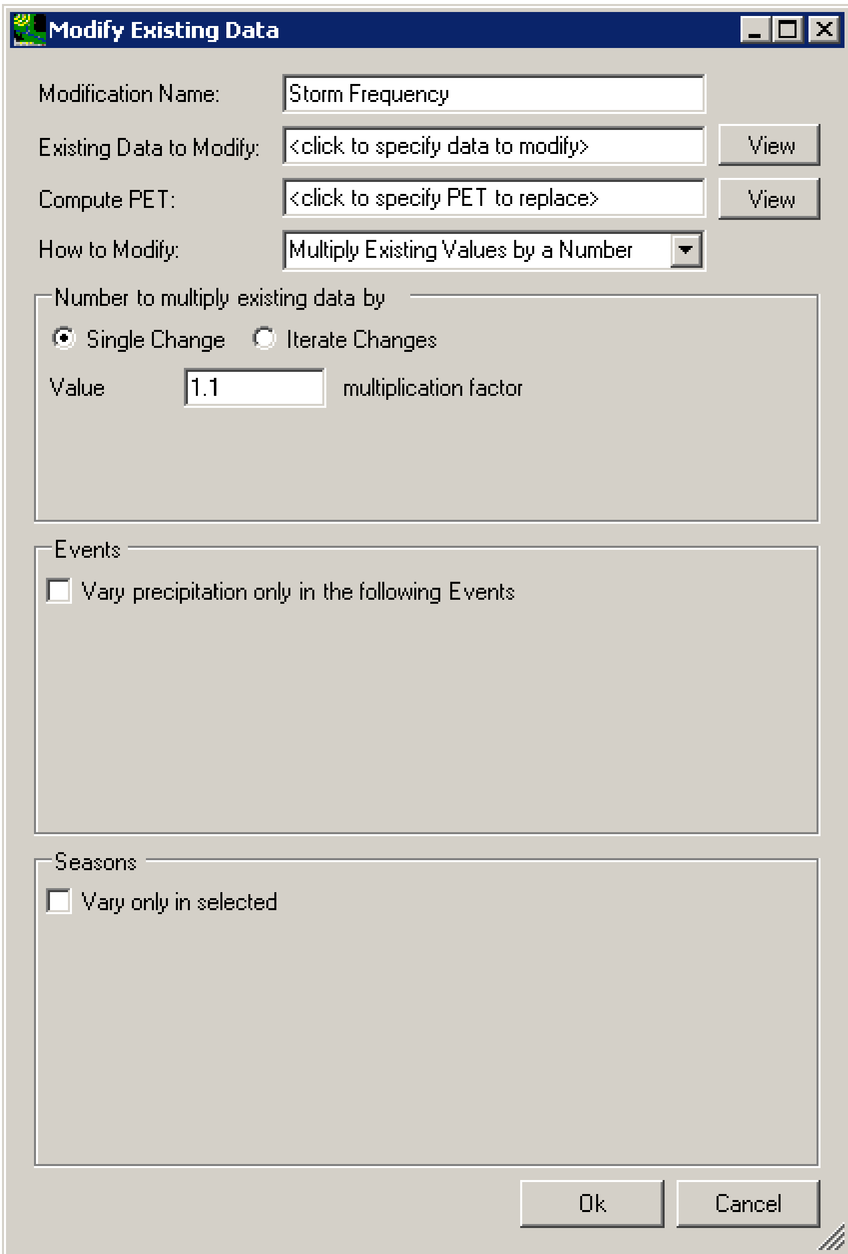
3.1.1.5 Add or Remove Storm Events

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

CAT has the ability to represent changes in storm frequency by adding or removing storms in a historical record. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.1.5.

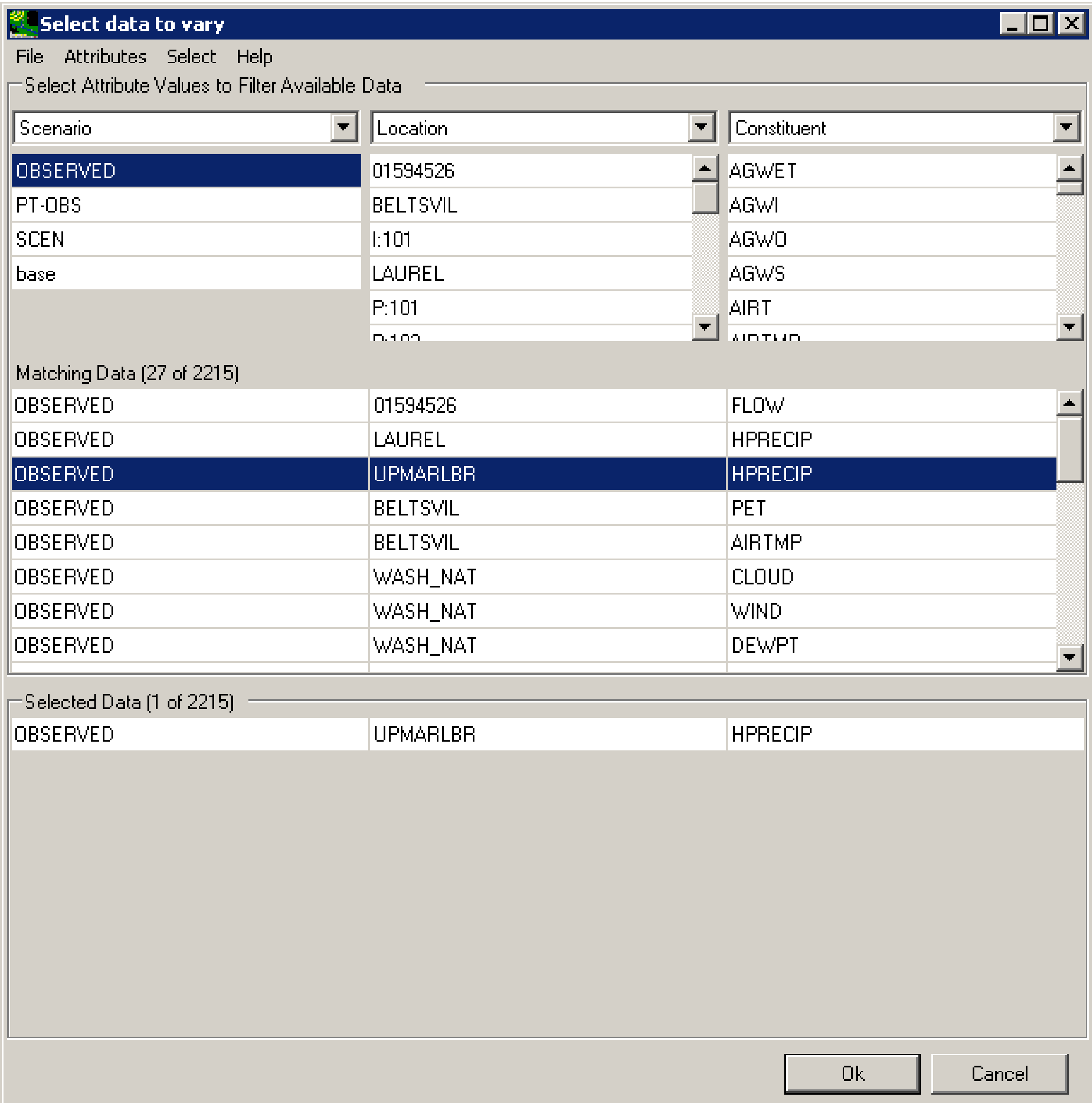
This tutorial will show how to make specifications to represent a change in storm frequency. The final result of the tutorial will be a climate scenario that increases the total volume of precipitation by a specified percent by adding storms during selected months in the year.

1. To begin creating a new climate scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. Begin defining this scenario by entering ‘Storm Frequency’ in the **Modification Name** field.



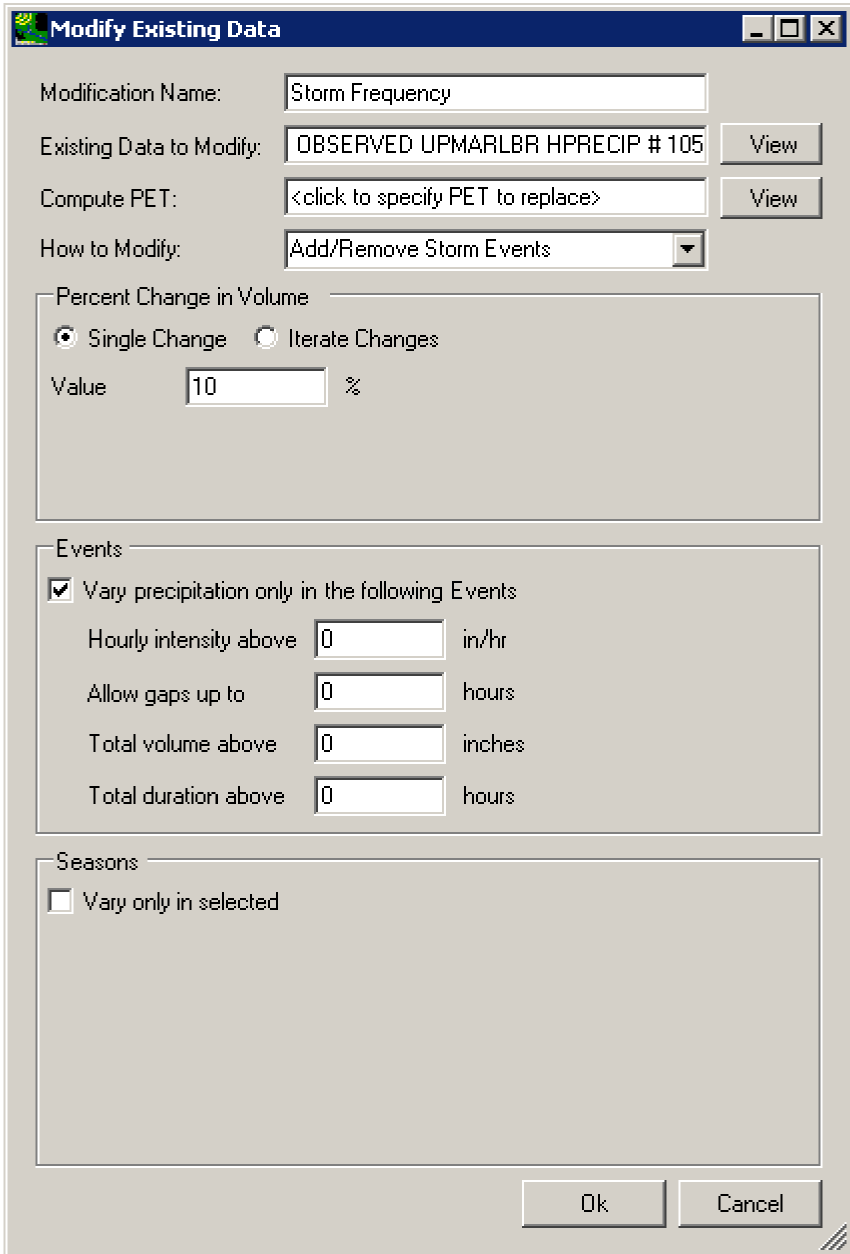
2. Since we will be modifying historical precipitation data, begin the selection process by clicking on the **OBSERVED** item under the **Scenario** list. In looking at the **Matching Data** list, note that there are two data sets with the **Constituent** name **HPRECIP** (hourly precipitation). The HSPF model used in this example is only applying precipitation from

the Upper Marlboro gage, so click on the data set with **UPMARLBR** and **HPRECIP** as the respective **Location** and **Constituent**. (Note: It is possible for more than one data set to be selected for use in defining a climate scenario.) When this data set has moved to the **Selected Data** list, click the **Ok** button.



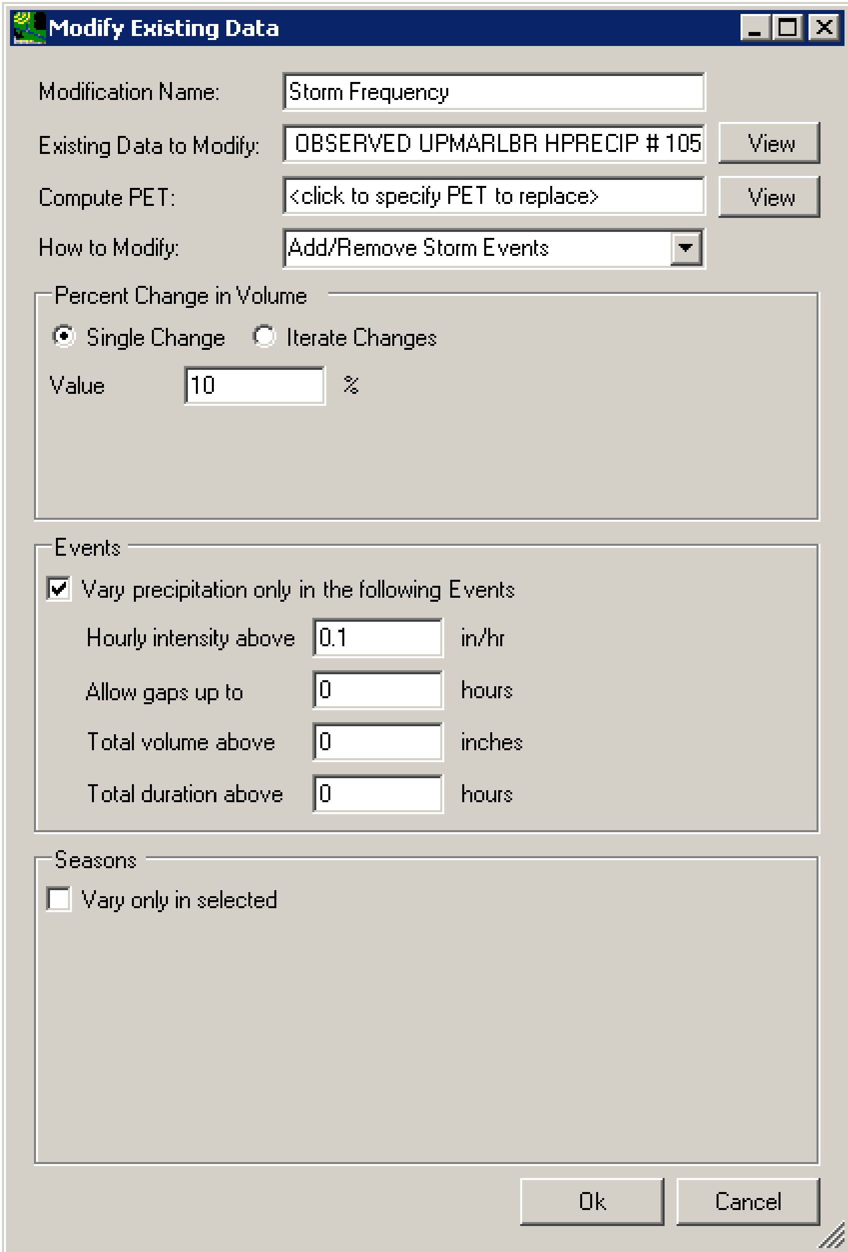
3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. The **Compute PET** box is for selecting the evapotranspiration dataset to modify when a temperature climate scenario is being defined and may be ignored for this example. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, select 'Add/Remove Storm

Events'. The form will be updated to allow for specification of storm intensity modifications.



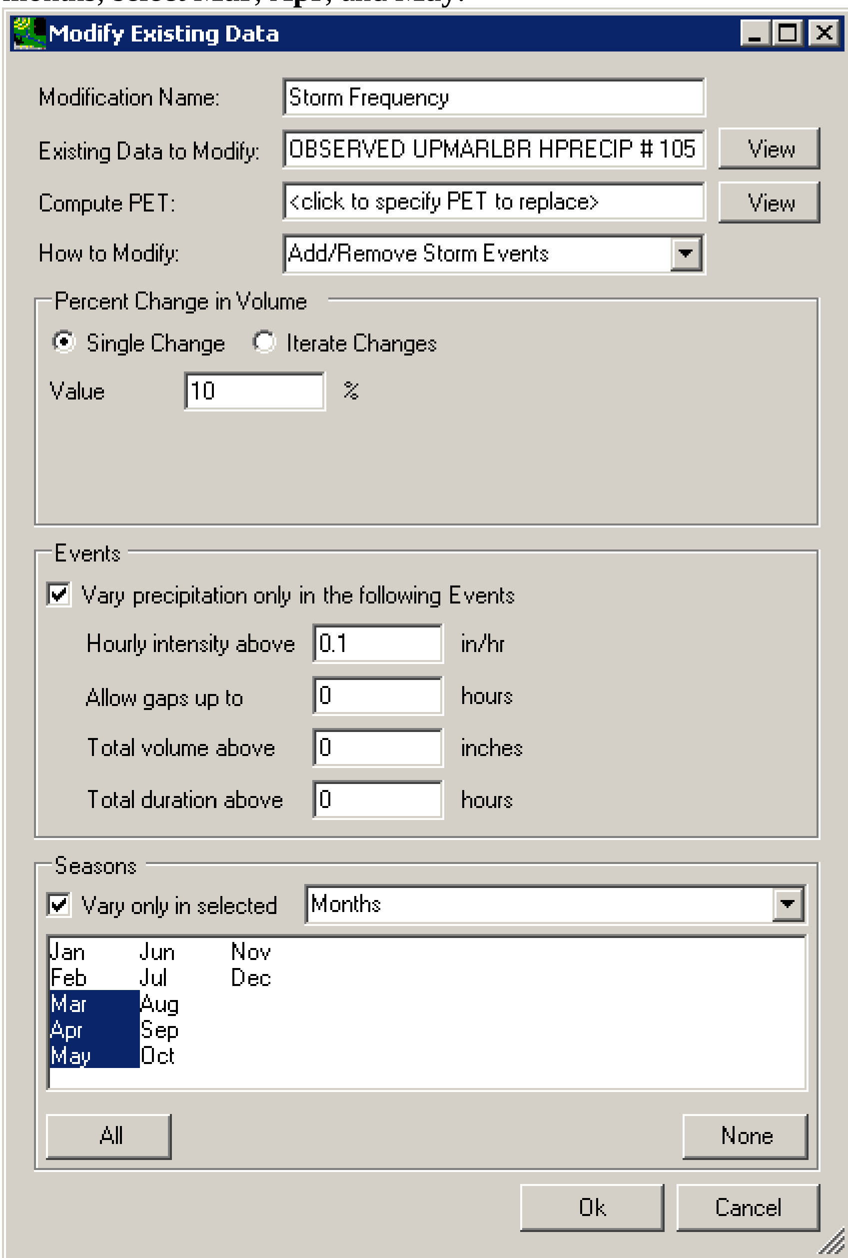
4. In the **Percent Change in Volume** frame leave the **Single Change** option selected and enter a value of '10' percent, indicating the percent change in the total water volume for the entire data set. In the **Events** frame, checking the **Vary precipitation only in the following Events** box causes four fields to be displayed for defining what qualifies as a storm event. Qualifying events will then be randomly selected and duplicated to meet the 10% increase specified above. (Note: "Unchecking" the **Vary precipitation only in the**

following Events box results in all precipitation values considered as events qualifying for duplication.) Values may be entered for any or all of the four elements. Enter ‘0.1’ in the **Total volume above** field, indicating that only events with greater than 0.1 inches/hour will be considered storm events.



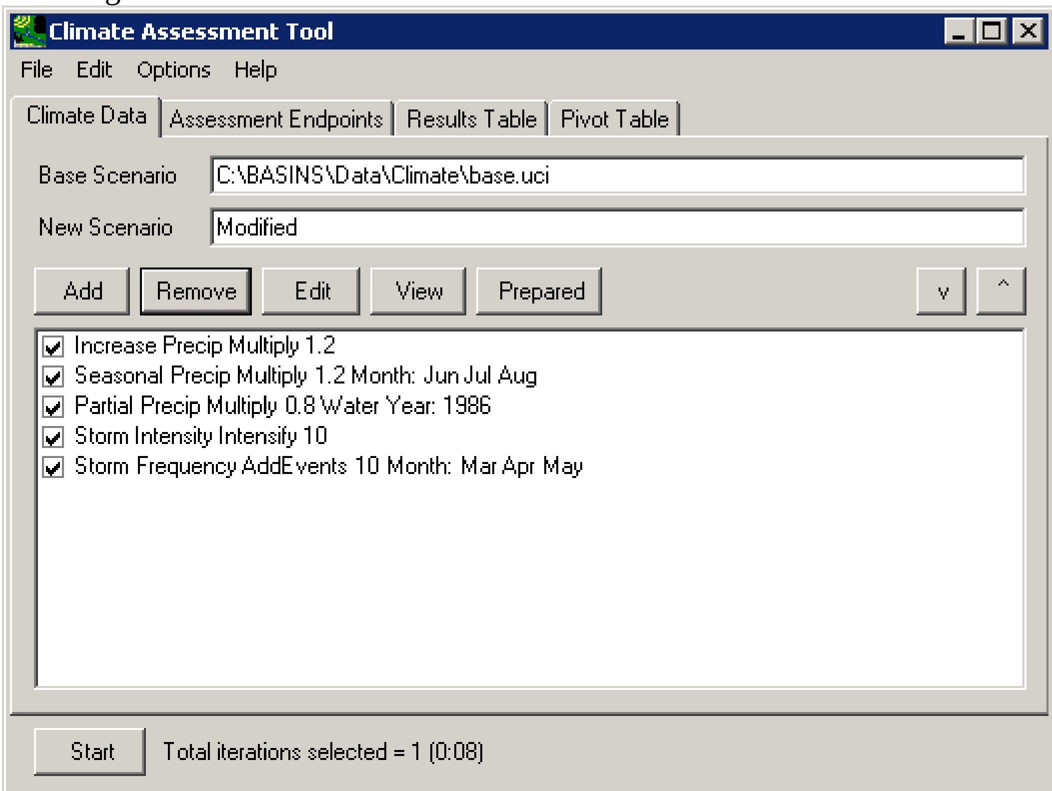
5. The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. Begin defining this subset by clicking on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the

item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. For this example, select the **Months** option and the second field will be populated with the months of the year. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. To represent increased storm frequency during spring months, select **Mar**, **Apr**, and **May**.



6. Click the **Ok** button at the bottom of the window. This scenario, as summarized on the main CAT form, will **Add** storms during **Mar Apr May** until a 10% increase in the data

set's original volume has been achieved.



7. Having completed defining this scenario, you may use the **View** button to see the values in the modified data sets. You may also want to save the state of CAT using the **File:Save Climate and Endpoints** menu option.

3.1.2 Modify Historical Air Temperature Records and Regenerate Evapotranspiration Record

As described in the Tools and Methods chapter, temperature records, and thus generated evapotranspiration records, may be modified in a variety of ways. The tutorials in this section demonstrate the following modifications:

- Applying a change to the entire temperature record and regenerating PET.
- Applying a seasonal change and regenerating PET.
- Applying a change to a portion of the temperature record and regenerating PET.

These tutorials all assume that the BASINS-CAT Set-up tutorial, in Section 3.0, has already been run.

3.1.2.1 Apply Increment or Decrement to Full Air Temperature Records and Regenerate Evapotranspiration Record

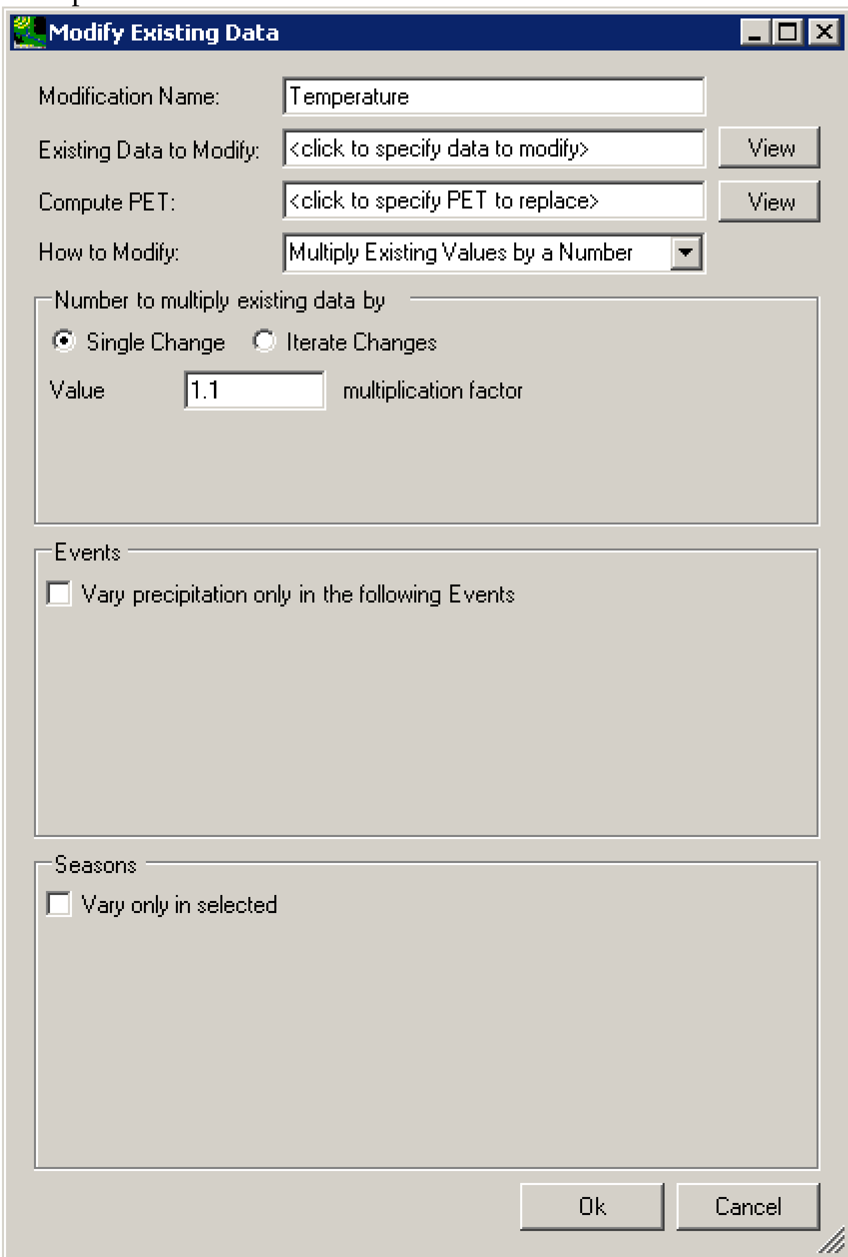
To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

The simplest method of modifying temperature is to apply a multiplier to historical values over the entire span of the model run. Potential Evapotranspiration (PET) data are then regenerated using the modified temperature values. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.2.1.

This tutorial will show how a single change may be applied to an entire historical air temperature data record and how PET data are regenerated from the modified data. The final result of the tutorial will be a climate adjustment that applies an increase to historical air temperature data and regenerates PET data for use as model input.

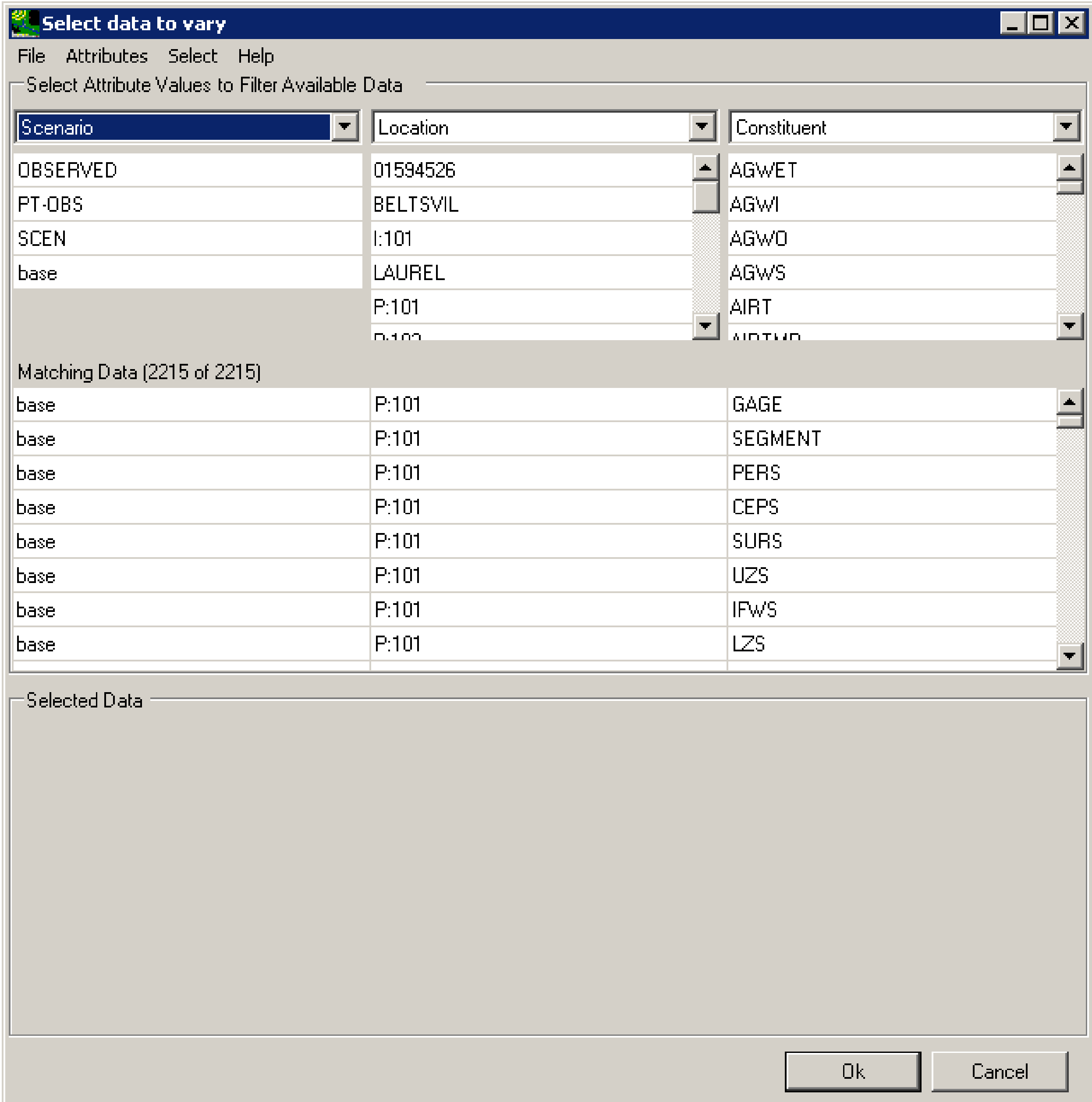
1. To begin creating a new climate adjustment, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this scenario by entering

‘Temperature’ in the **Modification Name** field.



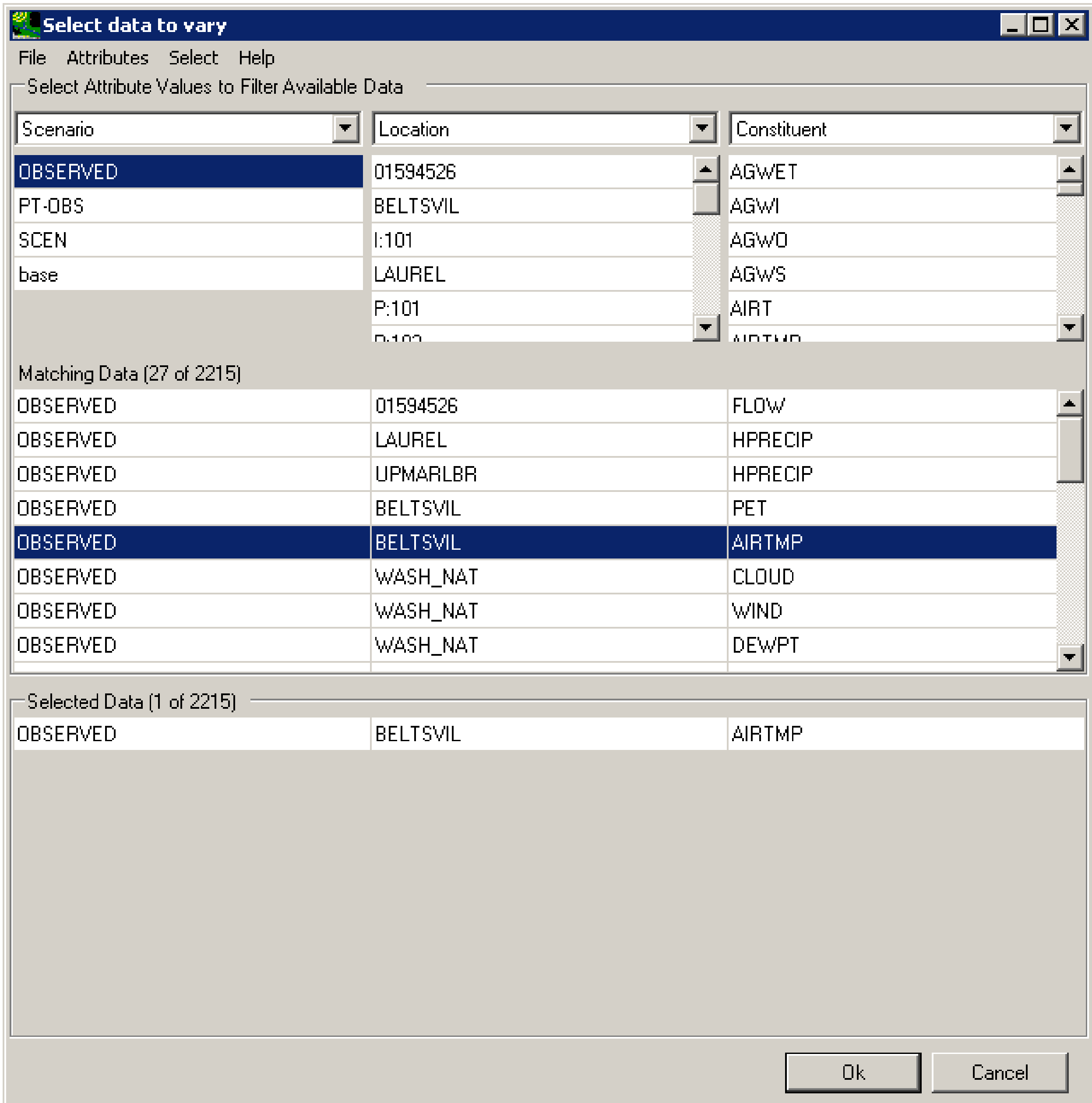
2. To select the air temperature data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. In the top third of this window, titled **Select Attribute Values to Filter Available Data**, you can filter the type of data to select by Scenario, Location, or Constituent. The data matching your selections will appear in the middle third of the window, titled **Matching Data**. To further filter the data, select one or more data sets from the **Matching Data** list, which will show up in the lower third of the window under **Selected Data**. If you would like to select all of the **Matching Data**, leave the **Selected Data** area blank. Click on individual data sets to

remove them from **Selected Data**.

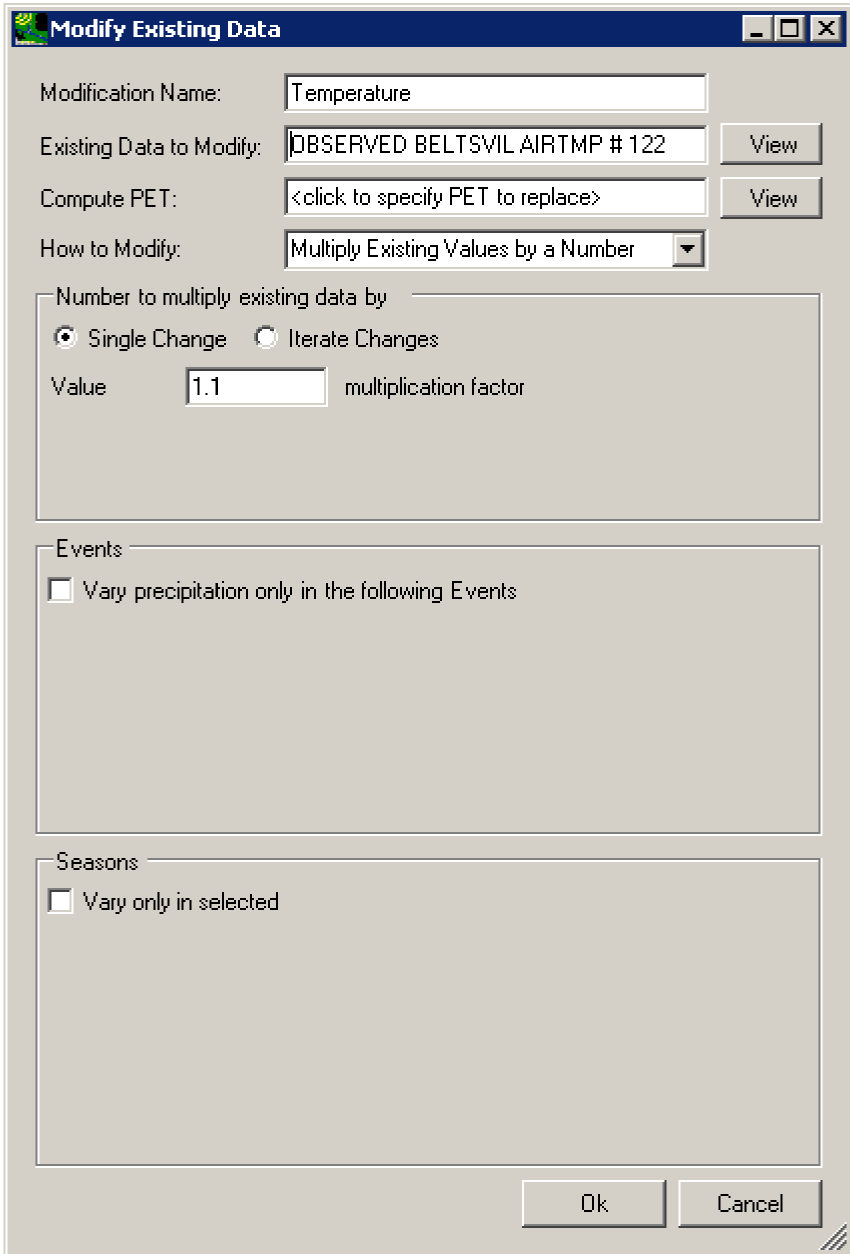


3. Begin the selection process by looking at the first column, labeled **Scenario**, in the **Select Attribute Values to Filter Available Data** frame. Click on the **OBSERVED** item and all data sets with a Scenario attribute of OBSERVED will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note the data set with the **Constituent** name **AIRTMP** (air temperature). Click on this data set and it will be

added to the **Selected Data** list. Click the **Ok** button to close the form.

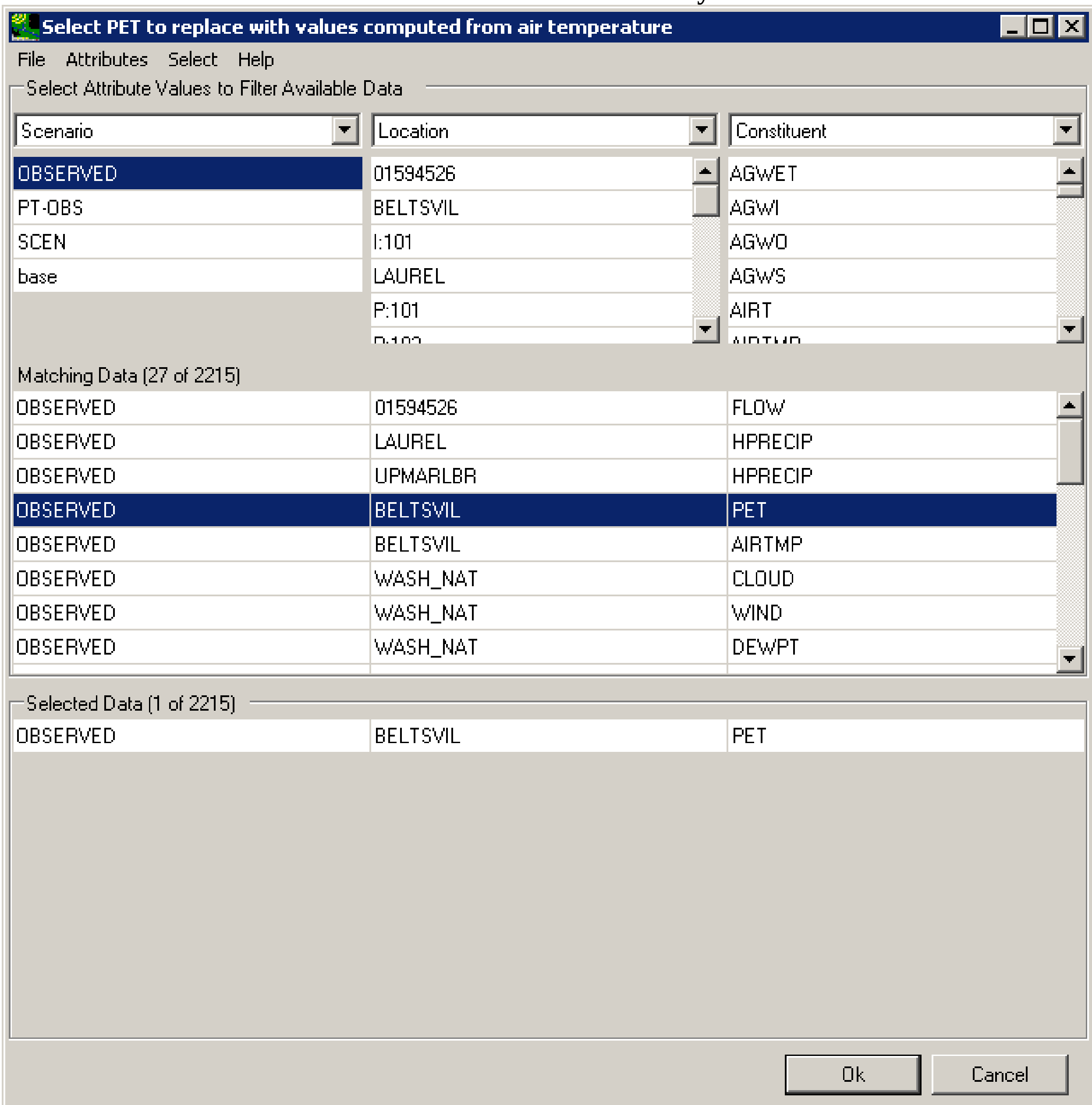


4. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. When modifying temperature it is necessary to also re-compute the Potential Evapotranspiration (PET) using the modified temperature data. Click in the **Compute PET** box to specify which PET data to re-compute.



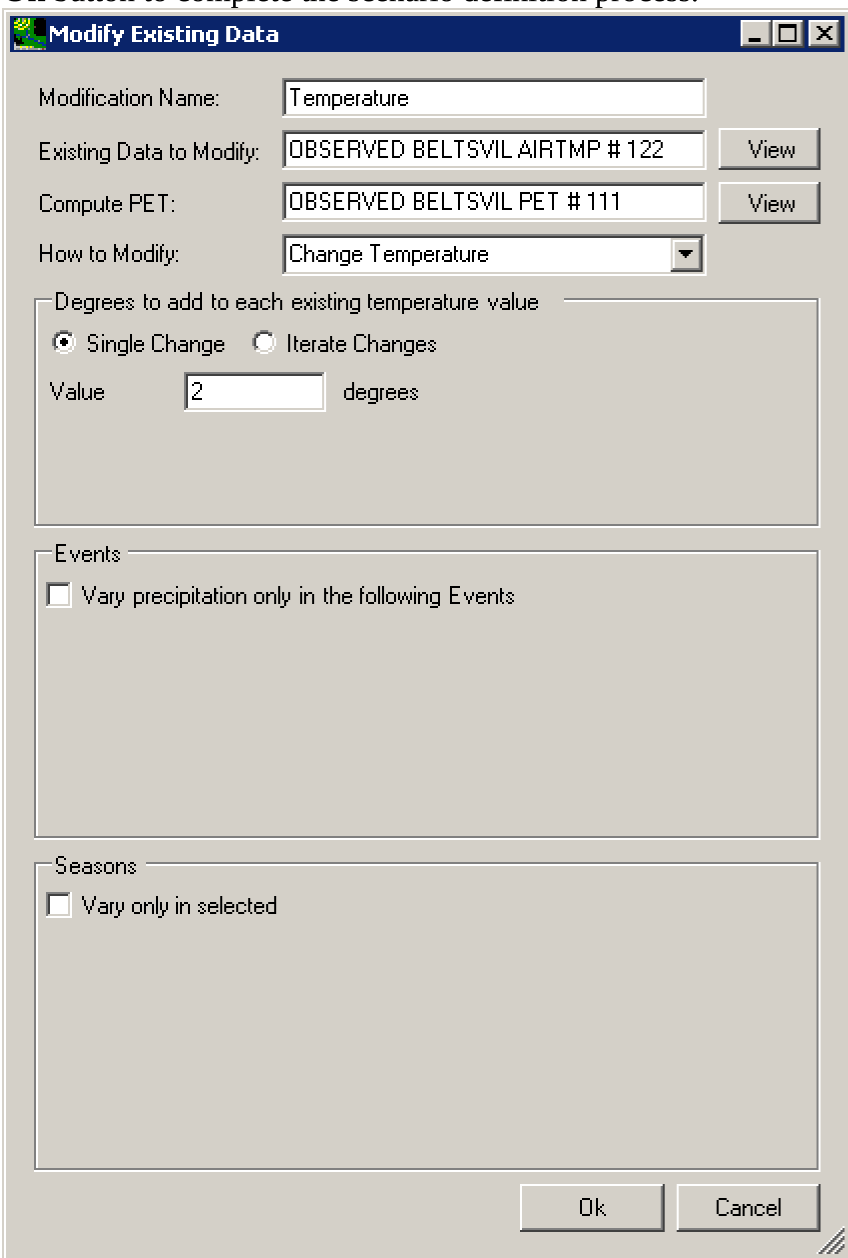
5. In the **Select data to vary** form, again click on the **OBSERVED** item in the **Scenario** column and then click the **OBSERVED BELTSVIL PET** data set from the **Matching**

Data list. Click the **Ok** button to close the **Select data to vary** form.

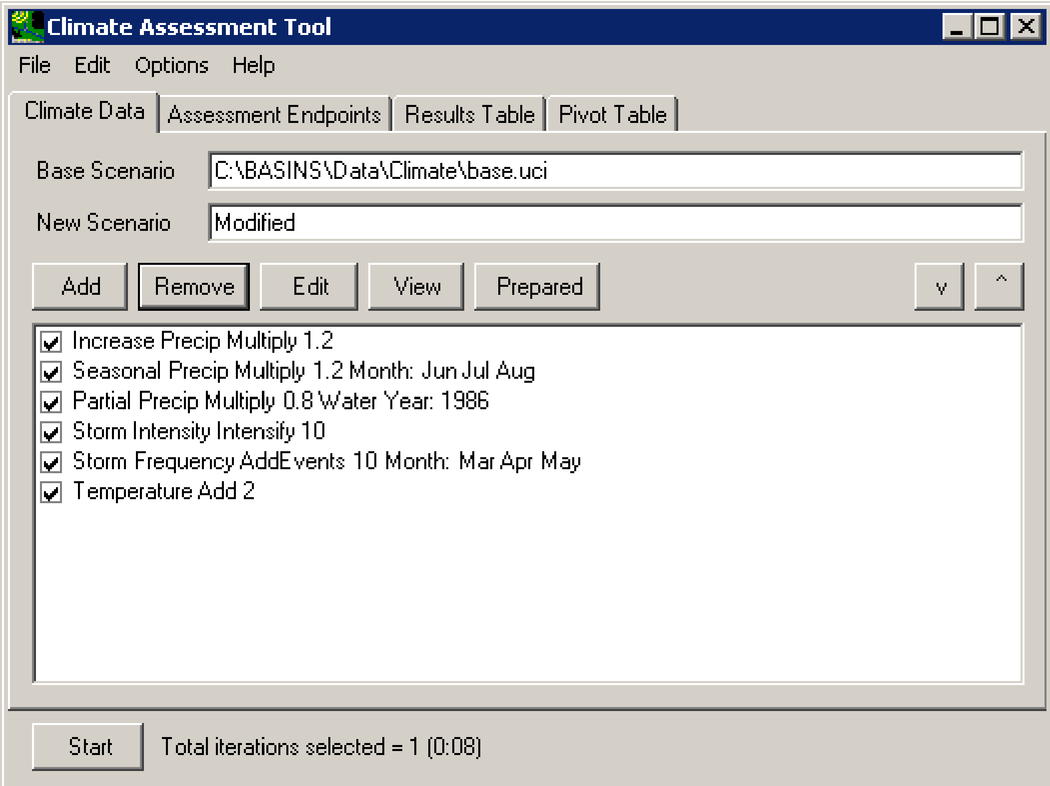


6. The **Modify Existing Data** form has been updated with a description of the selected data set in the **Compute PET** box. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, select the “Change Temperature” option. In the **Degrees to add to each existing temperature value** frame, there are two modification options: **Single Change** or **Iterate Changes**. The term ‘iterate’ as used here refers to the automation of multiple runs. The **Single Change** option will result in one adjustment applied to the temperature data set. The **Iterate Changes** option will result in a series of adjustments to the temperature data set and is used to create

"synthetic" climate change scenarios as described in Section 2.3.1.4. Use of this option is shown in the Tutorial found in Section 3.1.4 Create Synthetic Climate Change Scenarios. For this example, we will use the **Single Change** option. Enter '2' in the **Value** field, thus defining the amount to be added to all values in the temperature data set. Click the **Ok** button to complete the scenario definition process.



7. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario.



8. To complete this session, close the data listing and save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

3.1.2.2 Apply Seasonal Increment or Decrement to Air Temperature Records and Regenerate Evapotranspiration Record

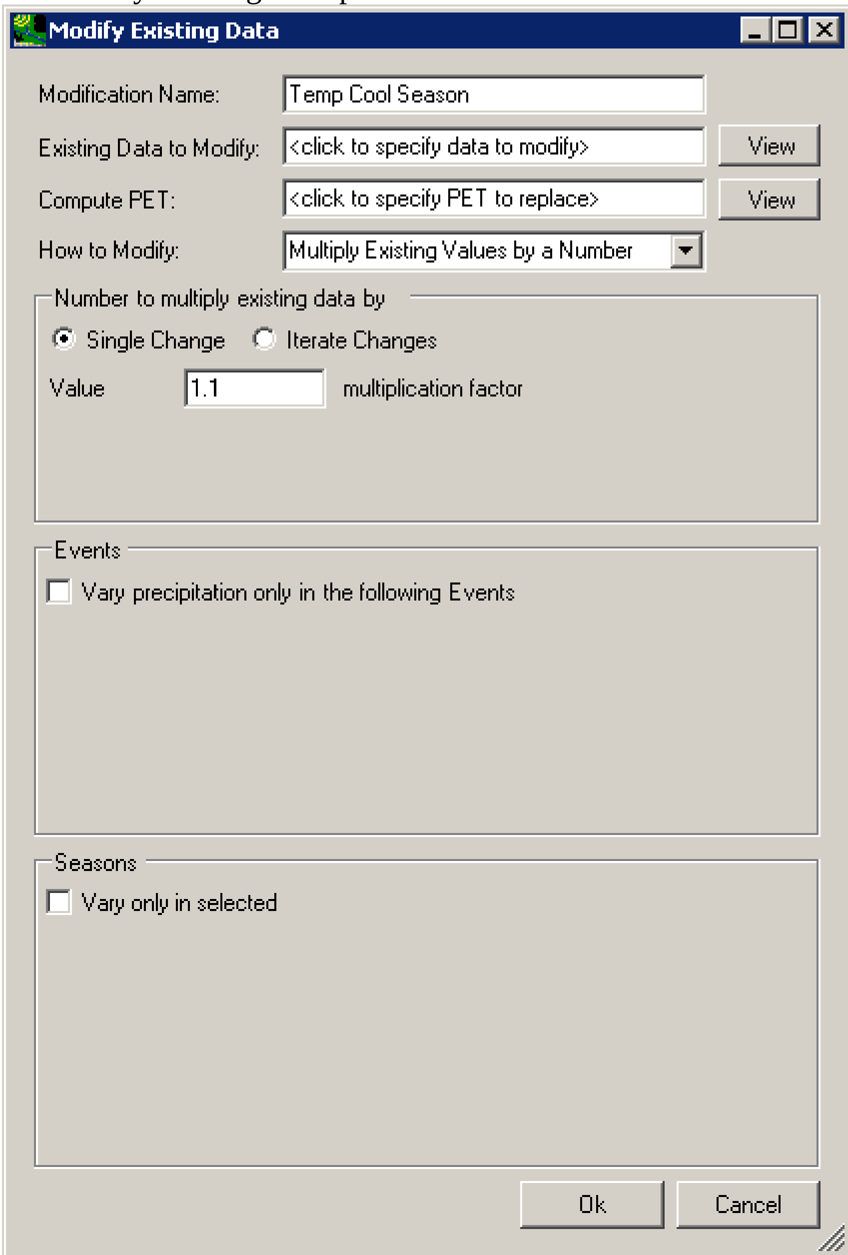
To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

As with precipitation, CAT allows for the modification of temperature (and computed PET) values for a specified portion of the year. With many climate models predicting larger temperature increases (in total degrees) in warmer months than in cooler, this capability can be very useful in representing varying patterns throughout the year. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.2.2.

This tutorial will show how a single change may be applied to a historical air temperature data record for a specified portion of the year and how PET data are regenerated from the modified data. The final result of the tutorial will be two climate adjustments, one for cool months and one for warm, that apply different increases to historical air temperature data and regenerate PET data for use as model input.

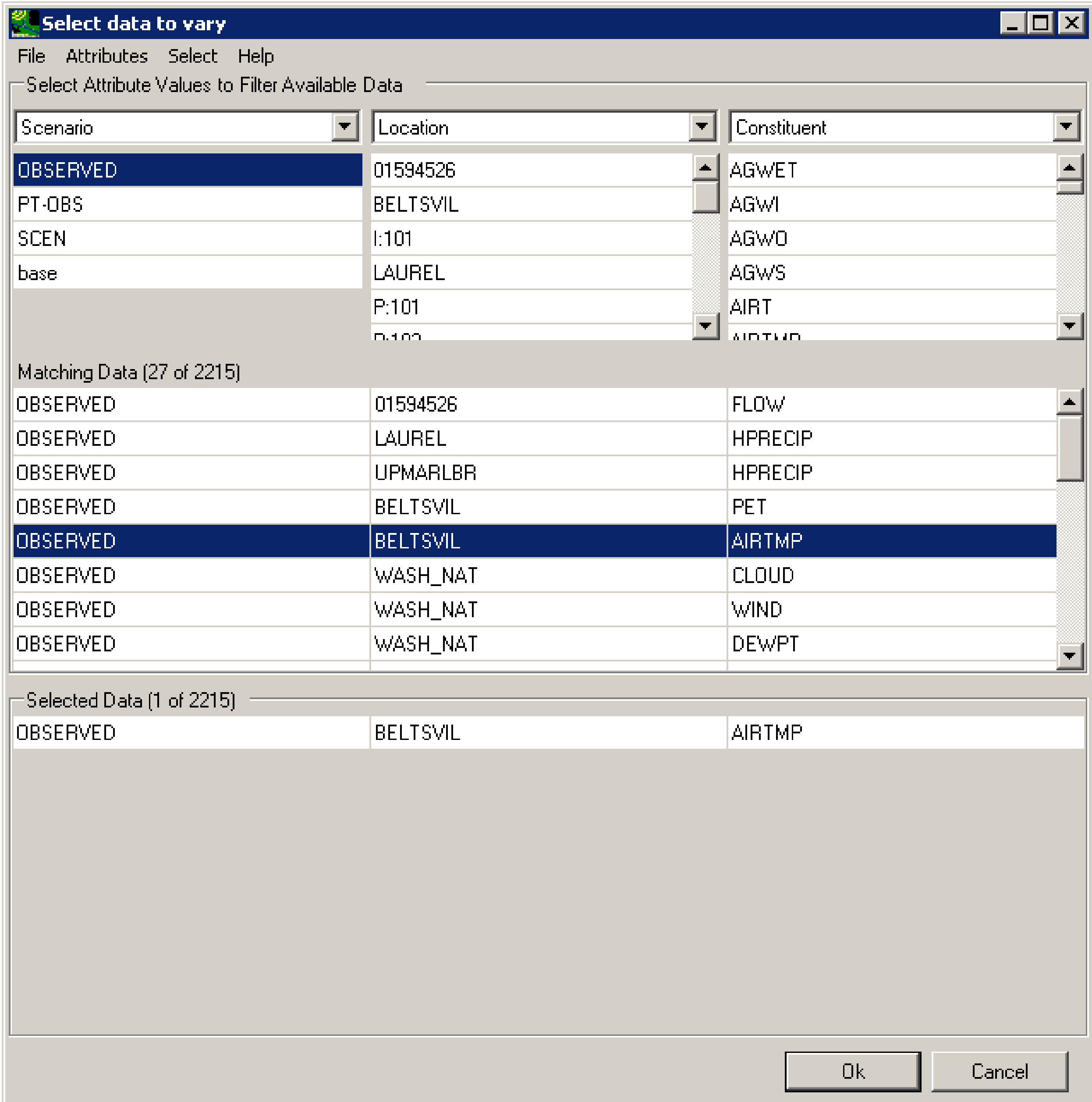
1. To begin creating the cool months temperature adjustment, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this

scenario by entering ‘Temp Cool Season’ in the **Modification Name** field.

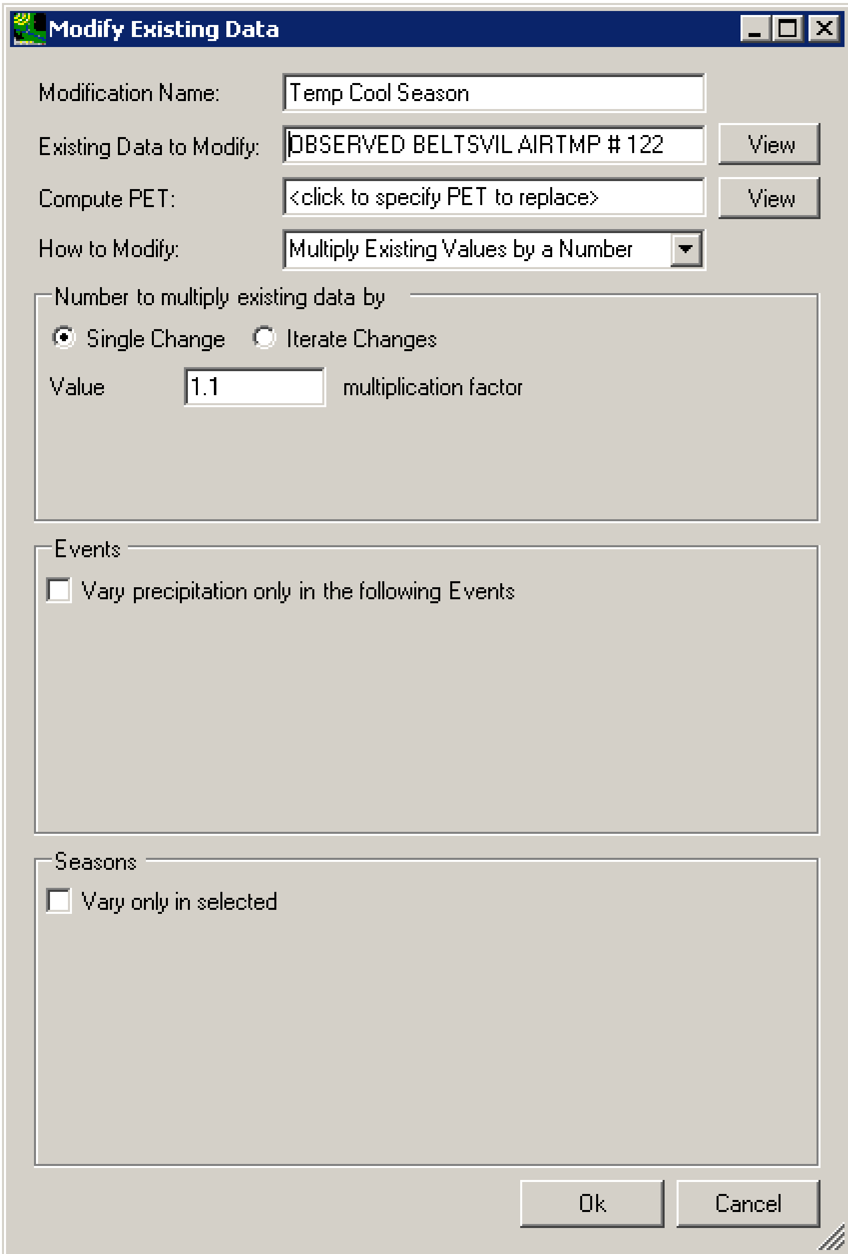


2. To select the air temperature data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.2.1. In the first column, under the **Scenario** label, click on the **OBSERVED** item and all data sets with a Scenario attribute of OBSERVED will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note the data set with the **Constituent** name **AIRTMP** (air temperature). Click on this data set and it will be added to the **Selected Data** list. Click

the **Ok** button to close the form.

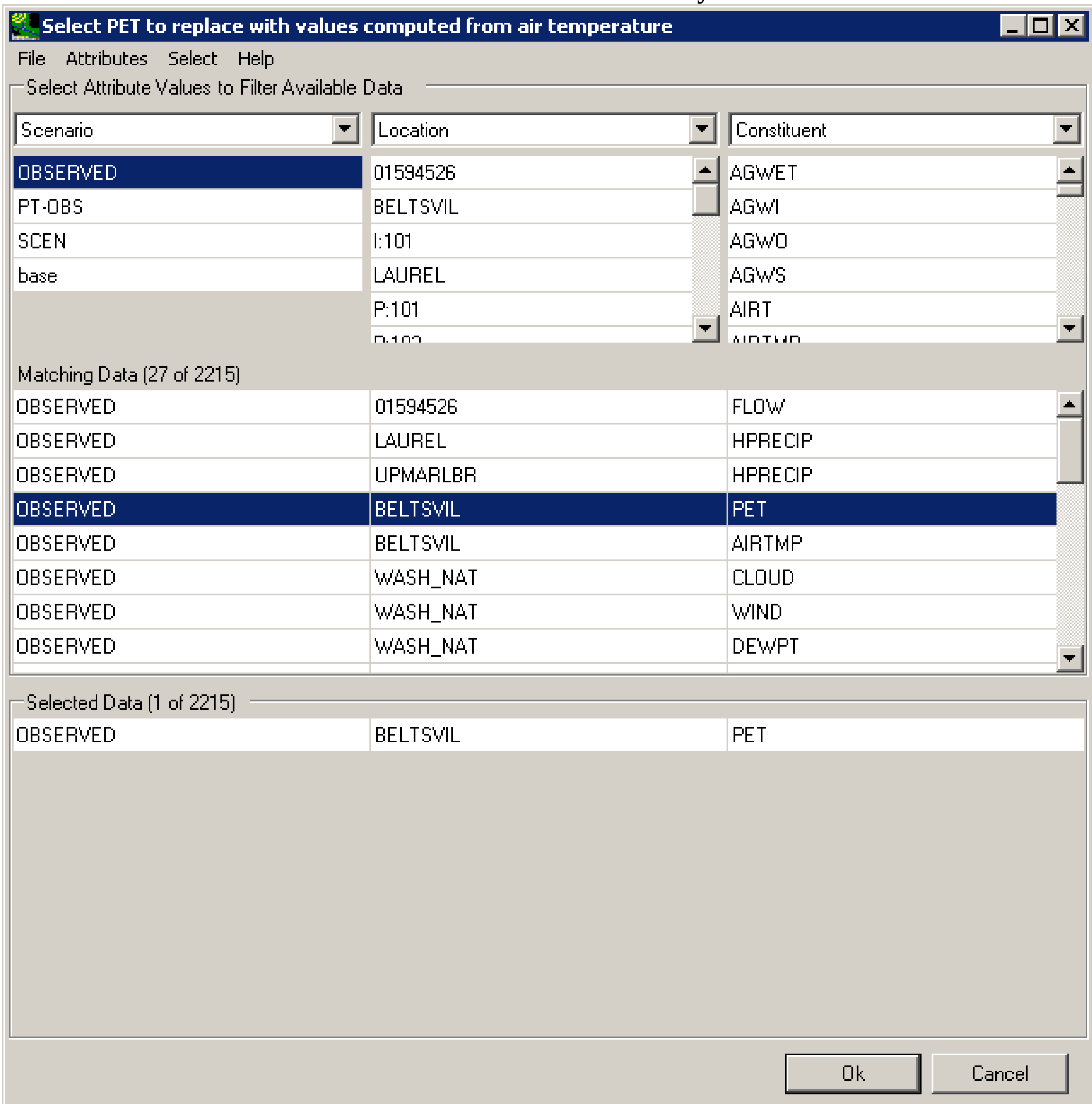


3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. When modifying temperature it is necessary to also re-compute the Potential Evapotranspiration (PET) using the modified temperature data. Click in the **Compute PET** box to specify which PET data to re-compute.



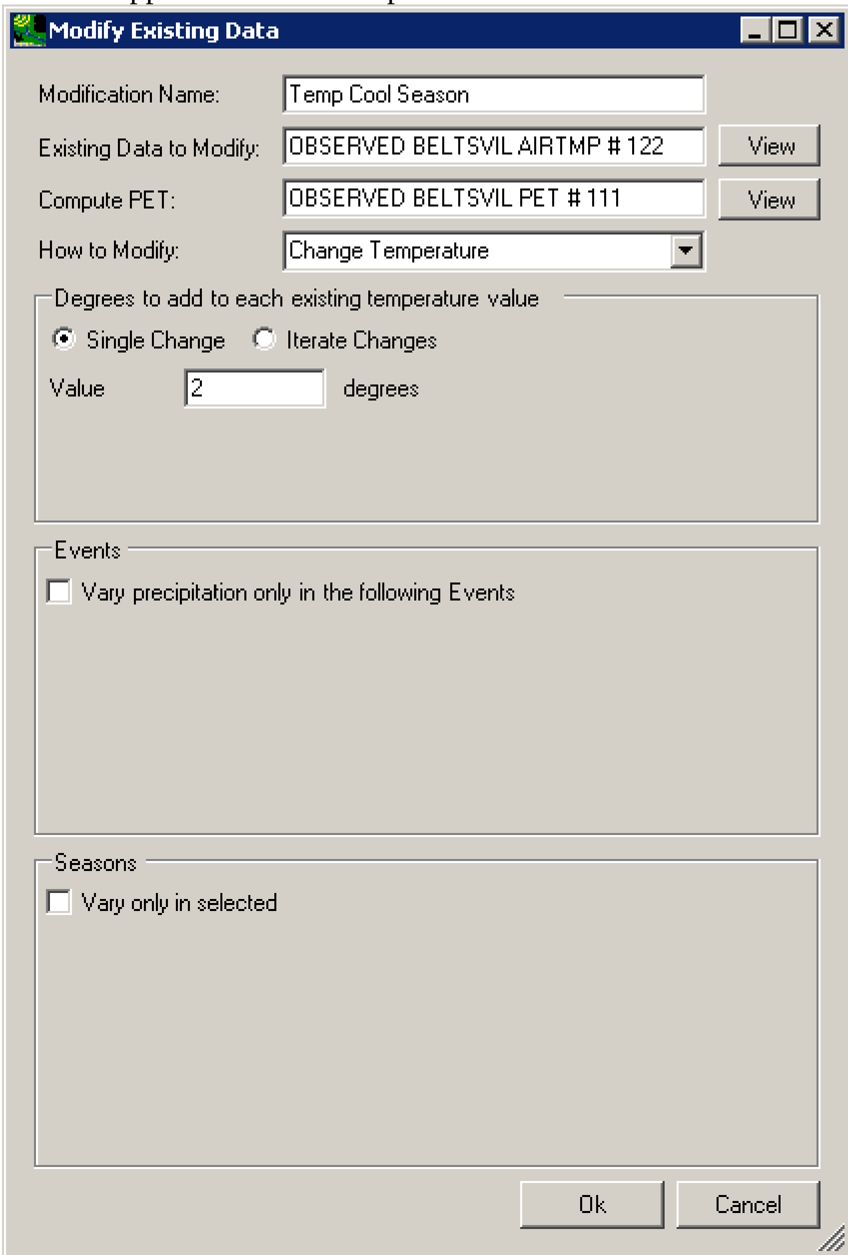
4. In the **Select data to vary** form, again click on the **OBSERVED** item in the **Scenario** column and then click the **OBSERVED BELTSVIL PET** data set from the **Matching**

Data list. Click the **Ok** button to close the **Select data to vary** form.



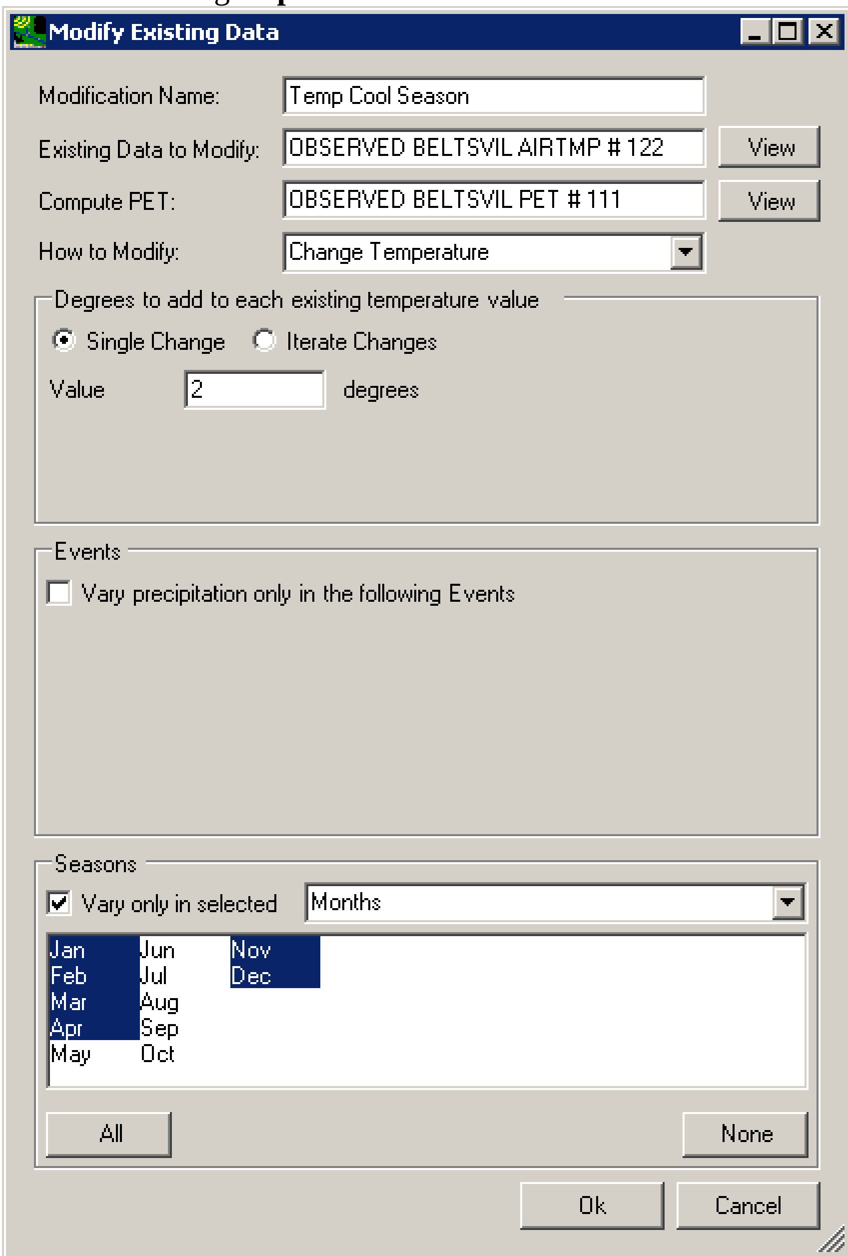
5. The **Modify Existing Data** form has been updated with a description of the selected data set in the **Compute PET** box. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, the "Change Temperature" option will be used. A detailed description of the **Degrees to add to each existing temperature value** frame is found in the tutorial in Section 3.1.2.1. For this example, we will use the **Single Change** option. Enter '2' in the **Value** field, which will be the temperature

increase applied to the air temperature values in the season defined in the next step.



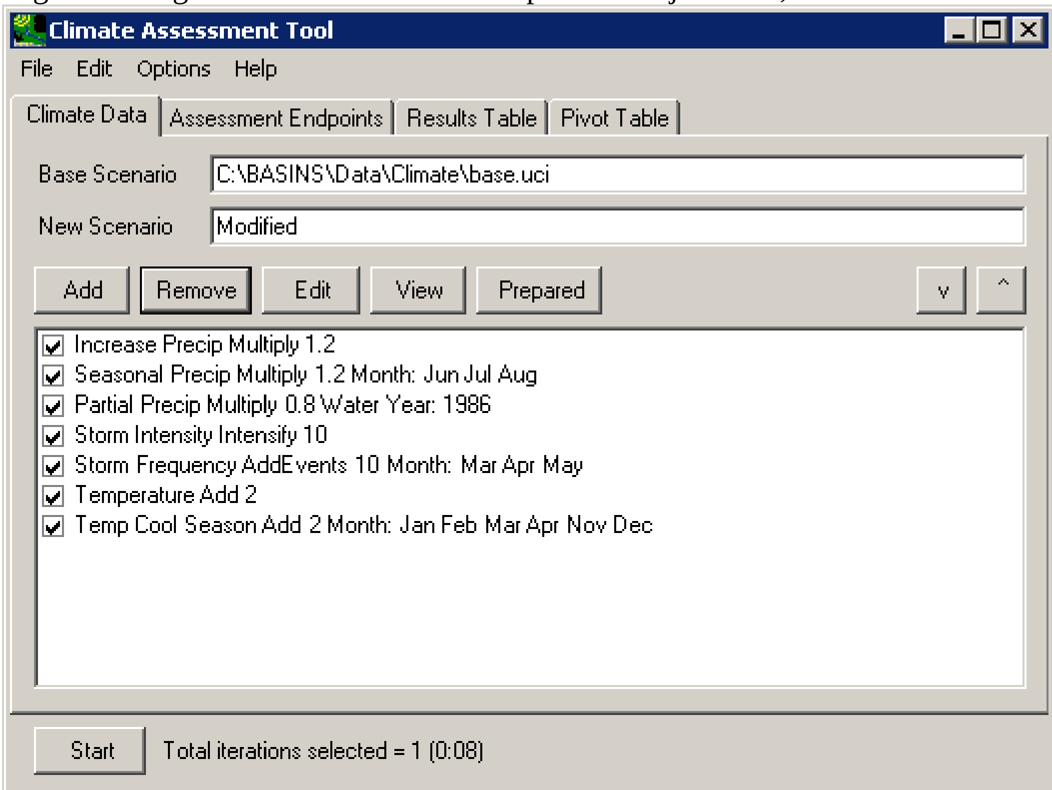
6. The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. Begin defining this subset by clicking on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. For this example, select the **Months** option and the second field

will be populated with the months of the year. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. To apply the 2 degree increase to cooler months, select **Nov** through **Apr**.



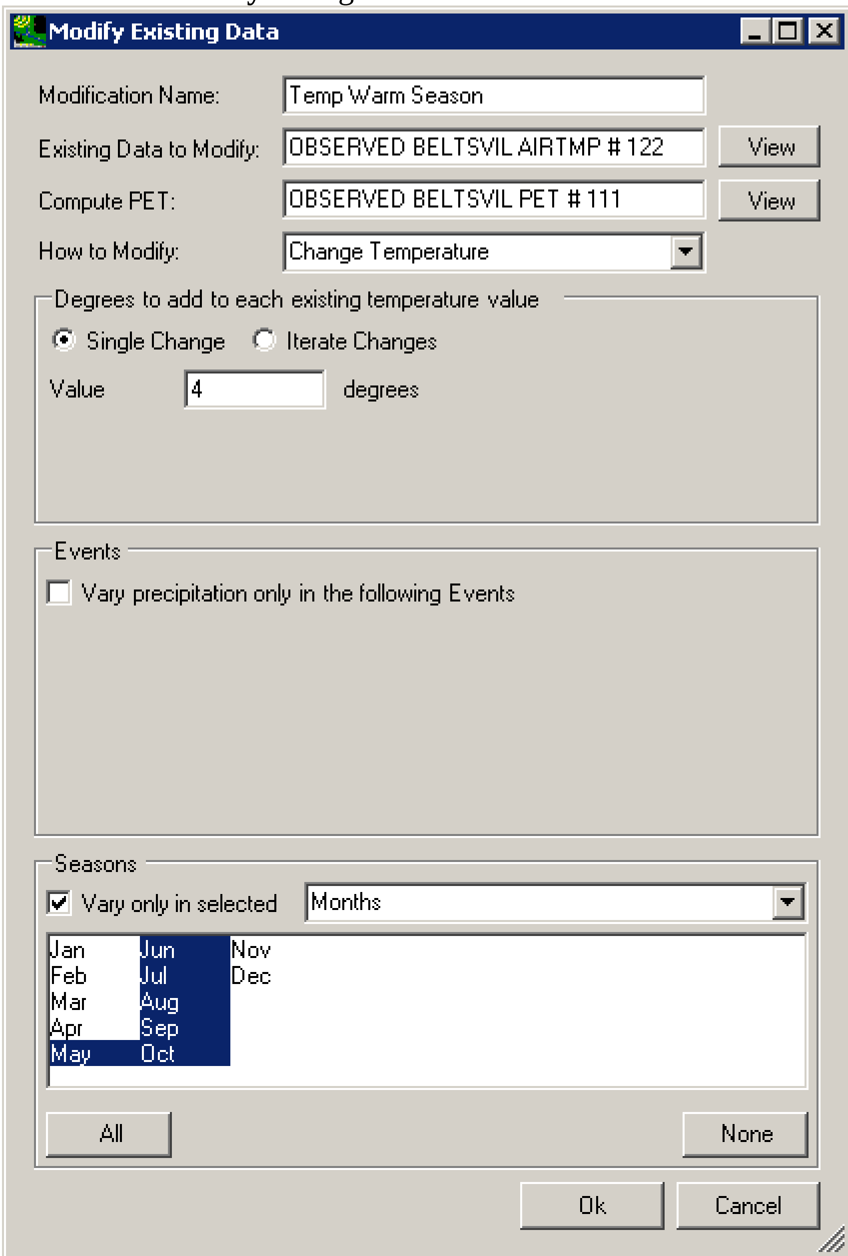
7. Click the **Ok** button to complete defining the cooler month's temperature adjustment. The newly defined adjustment will be shown on the **Climate Assessment Tool** form. To

begin defining the warm month's air temperature adjustment, click the **Add** button again.

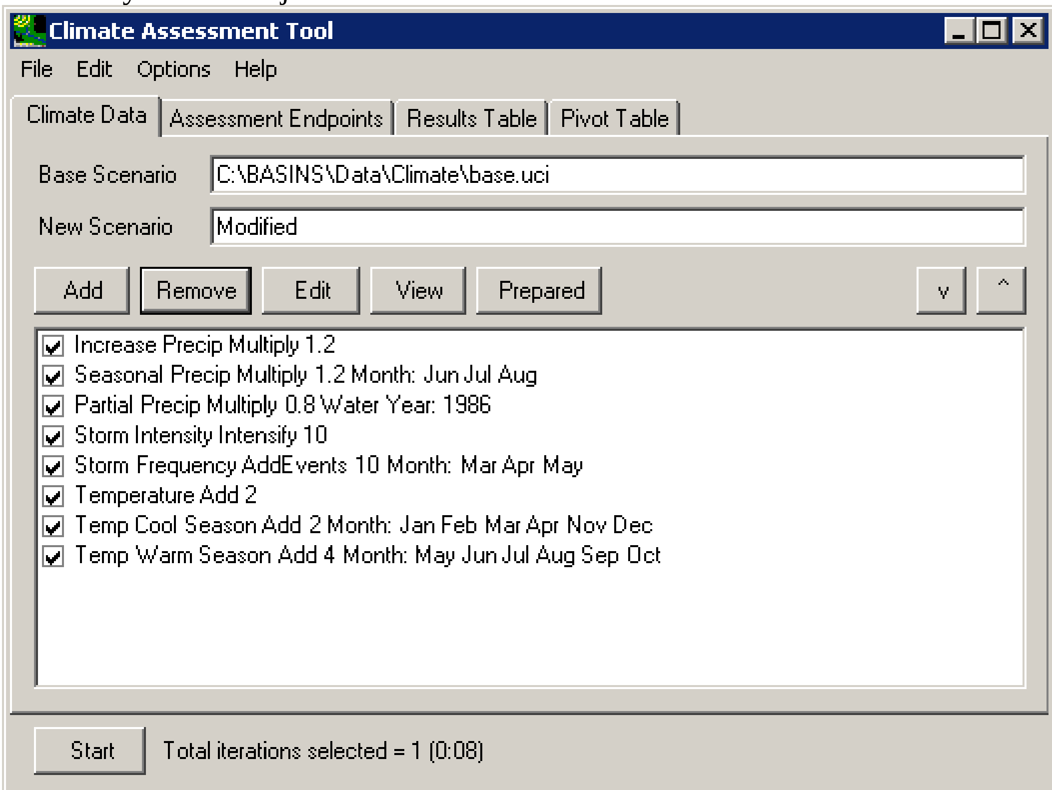


8. From the **Modify Existing Data** form, enter 'Temp Warm Season' in the **Modification Name** field. Next, repeat steps 2 - 4 to select the same air temperature and PET data sets as before. For the warm month's adjustment, we will apply a 4 degree increase to the historical data. Select **Change Temperature** from the **How to Modify** list and then enter '4' in the **Value** field. In the **Seasons** frame, again select **Months** from the first list

and then select **May** through **Oct**.



9. Click the **Ok** button to complete defining the warm month's temperature adjustment. The newly defined adjustment will be shown on the **Climate Assessment Tool** form.



10. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

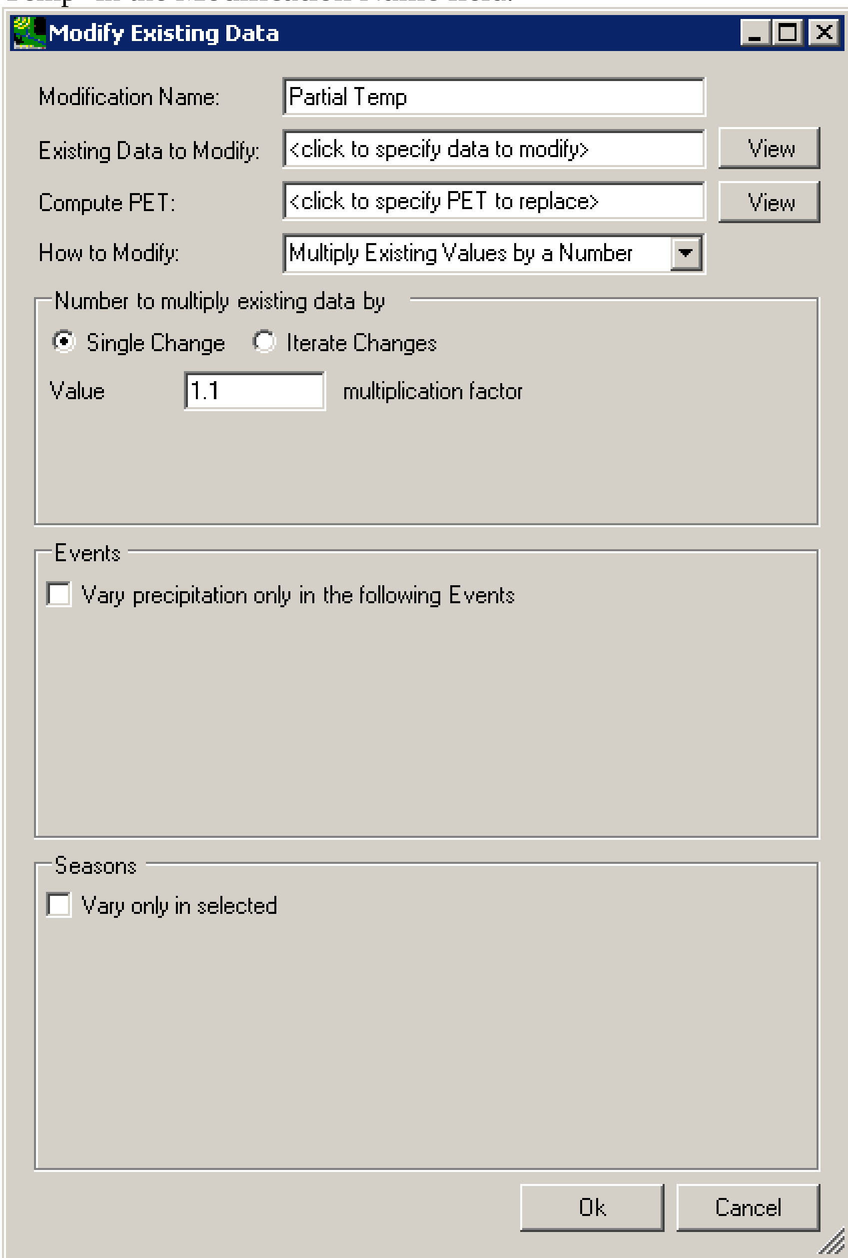
3.1.2.3 Adjust Partial Record and Regenerate Evapotranspiration Record

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

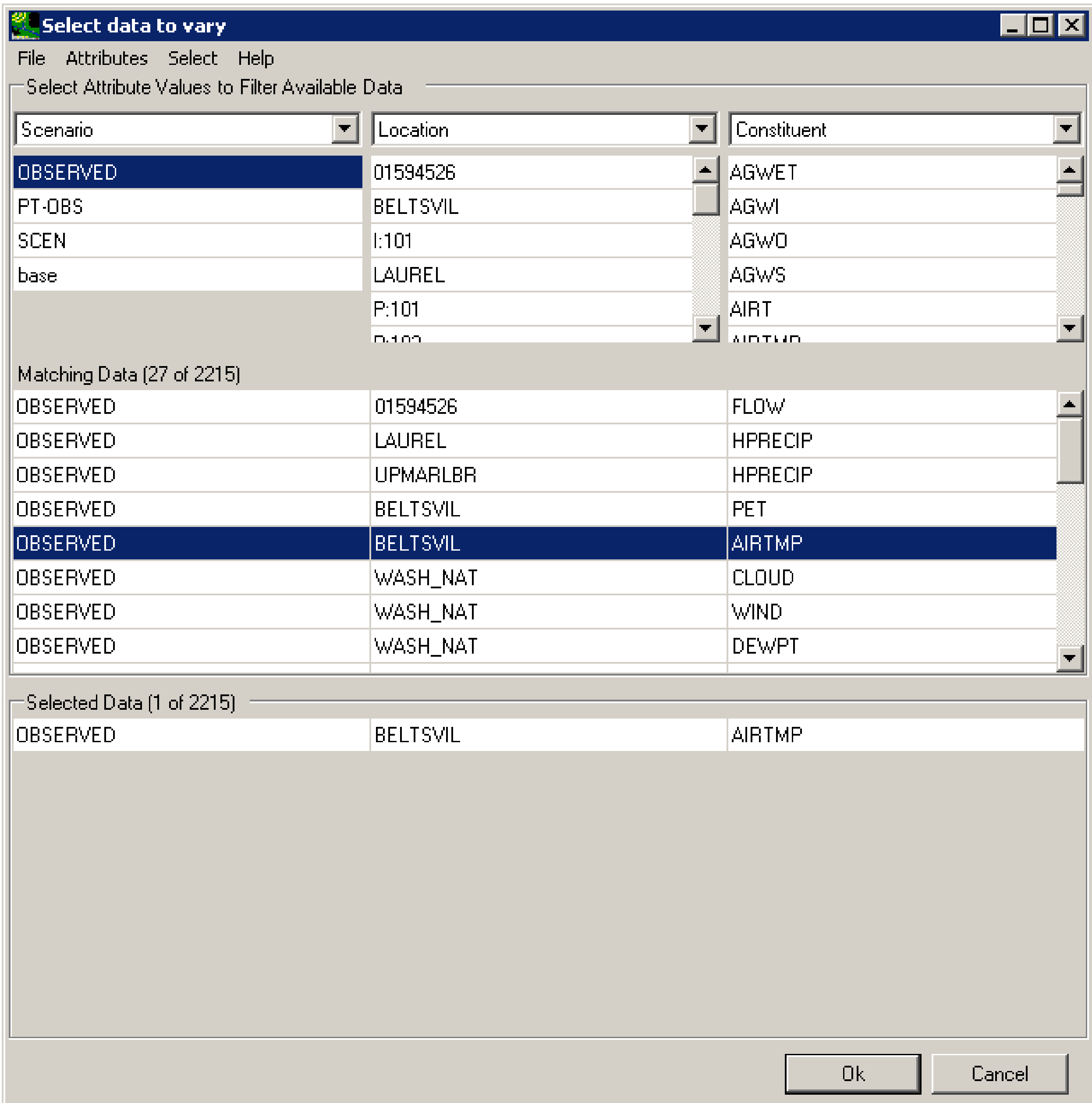
A common climate scenario need is to adjust historical values during a particular portion of the model run. For example, investigating the impacts of drought may include increasing the air temperature values, and re-computing PET values, for a specified year. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.2.3.

This tutorial will show how a single change may be applied to a historical air temperature data record for a specified portion of the model run and how PET data are regenerated from the modified data. The final result of the tutorial will be a climate adjustment that increases historical air temperature data and regenerates PET data for a single year of a model run.

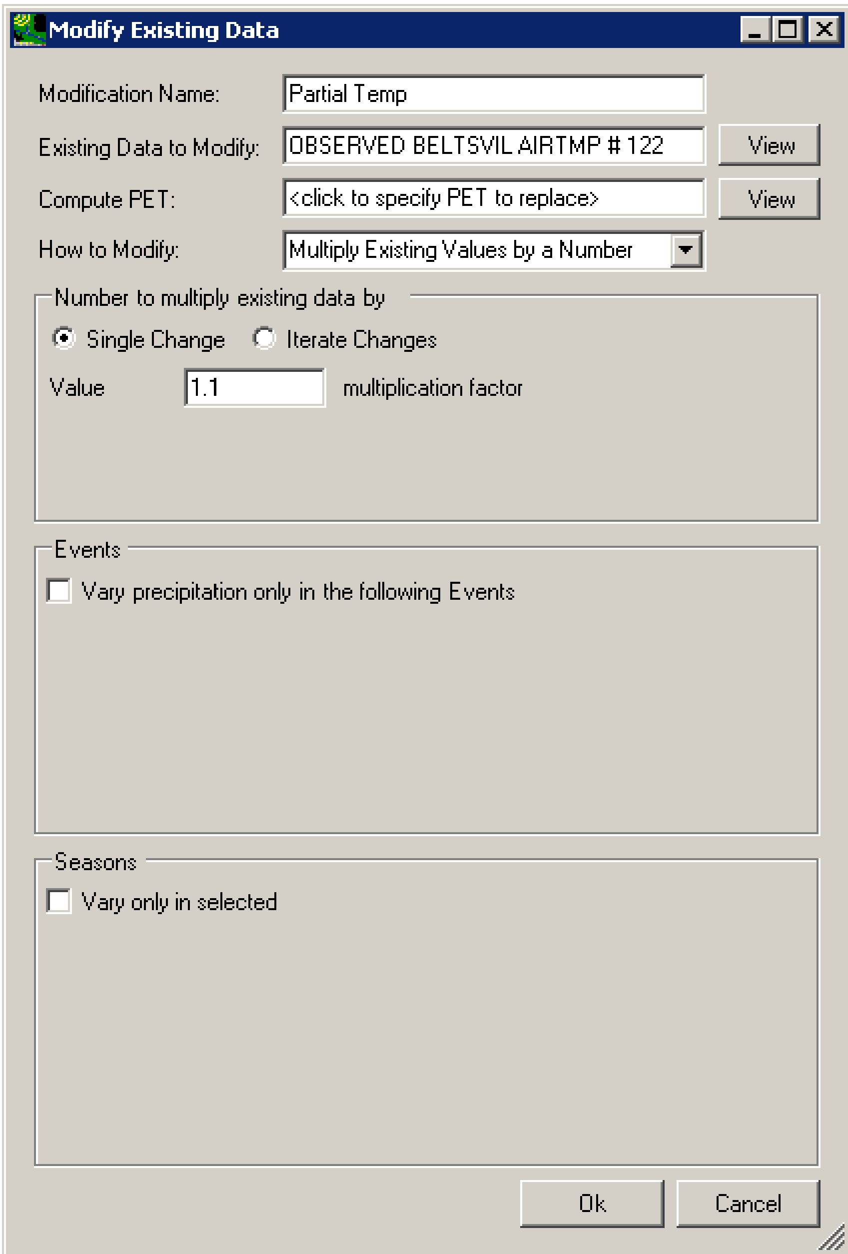
1. To begin creating a new climate scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this scenario by entering ‘Partial Temp’ in the **Modification Name** field.



2. To select the air temperature data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.2.1. In the first column, under the **Scenario** label, click on the **OBSERVED** item and all data sets with a Scenario attribute of OBSERVED will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note the data set with the **Constituent** name **AIRTMP** (air temperature). Click on this data set and it will be added to the **Selected Data** list. Click the **Ok** button to close the form.

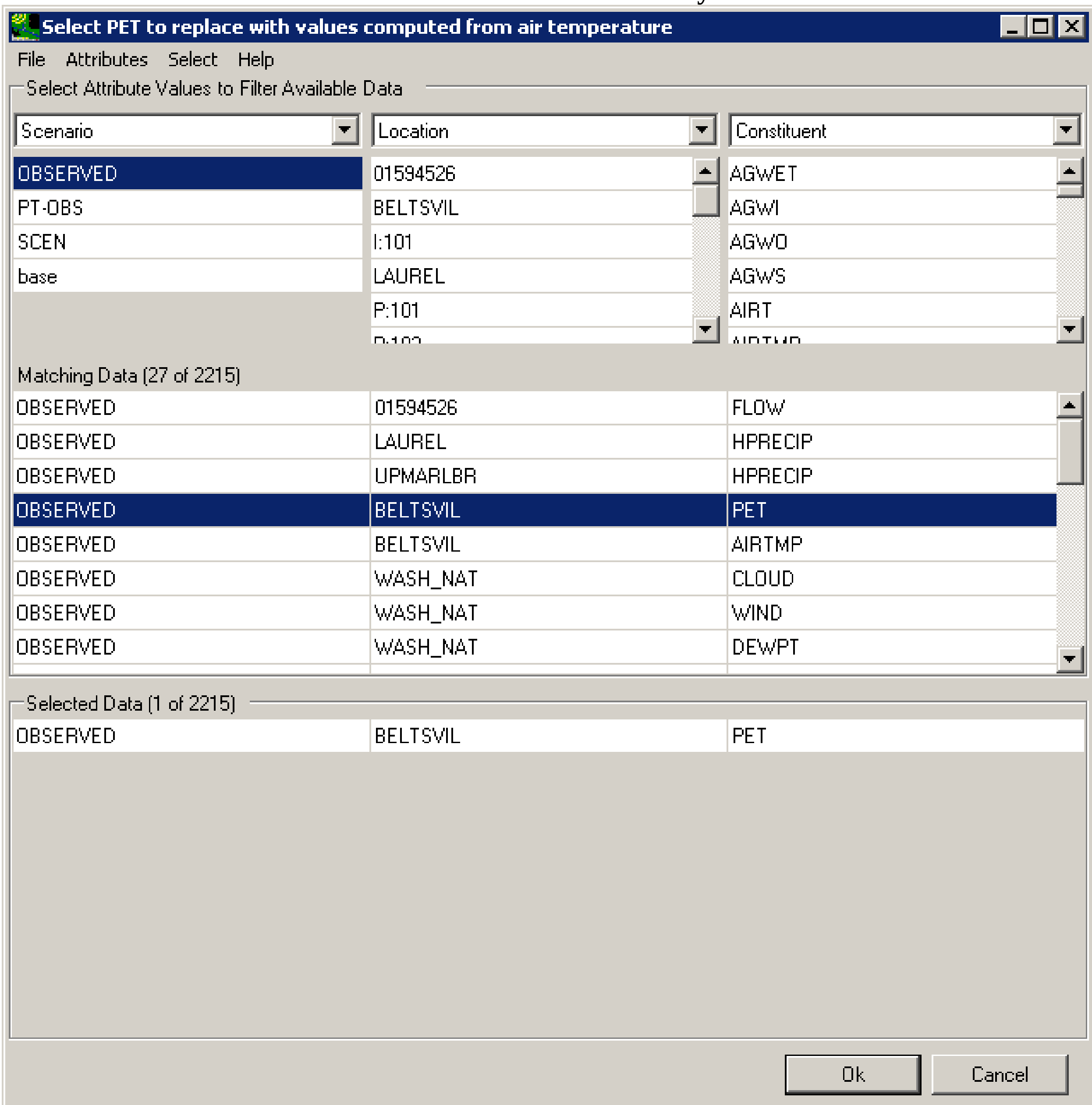


3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. When modifying temperature it is necessary to also re-compute the Potential Evapotranspiration (PET) using the modified temperature data. Click in the **Compute PET** box to specify which PET data to re-compute.



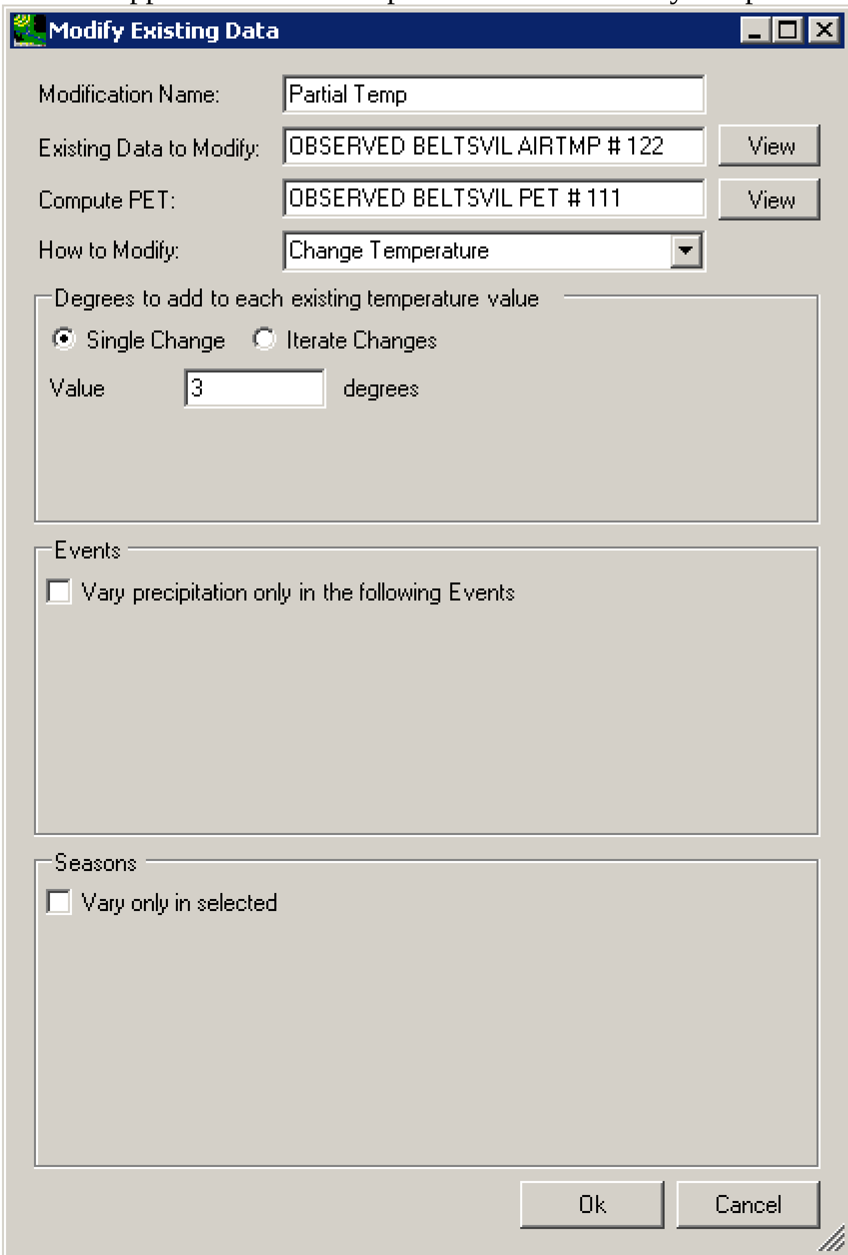
4. In the **Select data to vary** form, again click on the **OBSERVED** item in the **Scenario** column and then click the **OBSERVED BELTSVIL PET** data set from the **Matching**

Data list. Click the **Ok** button to close the **Select data to vary** form.



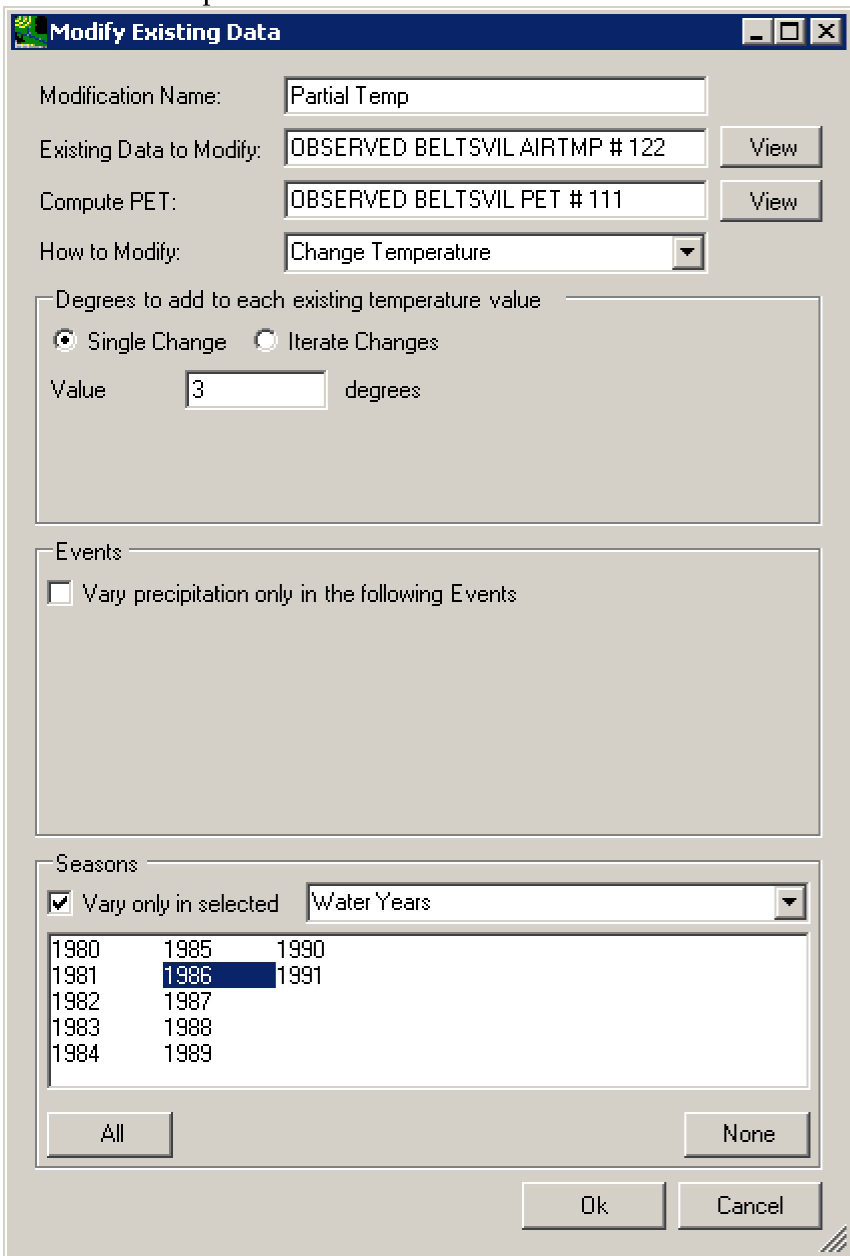
5. The **Modify Existing Data** form has been updated with a description of the selected data set in the **Compute PET** box. The **How to Modify** box contains a list of methods for modifying the data-set values. For this example, the “Change Temperature” option will be used. A detailed description of the **Degrees to add to each existing temperature value** frame is found in the tutorial in Section 3.1.2.1. For this example, we will use the **Single Change** option. Enter ‘3’ in the **Value** field, which will be the temperature

increase applied to the air temperature values in the year specified in the next step.

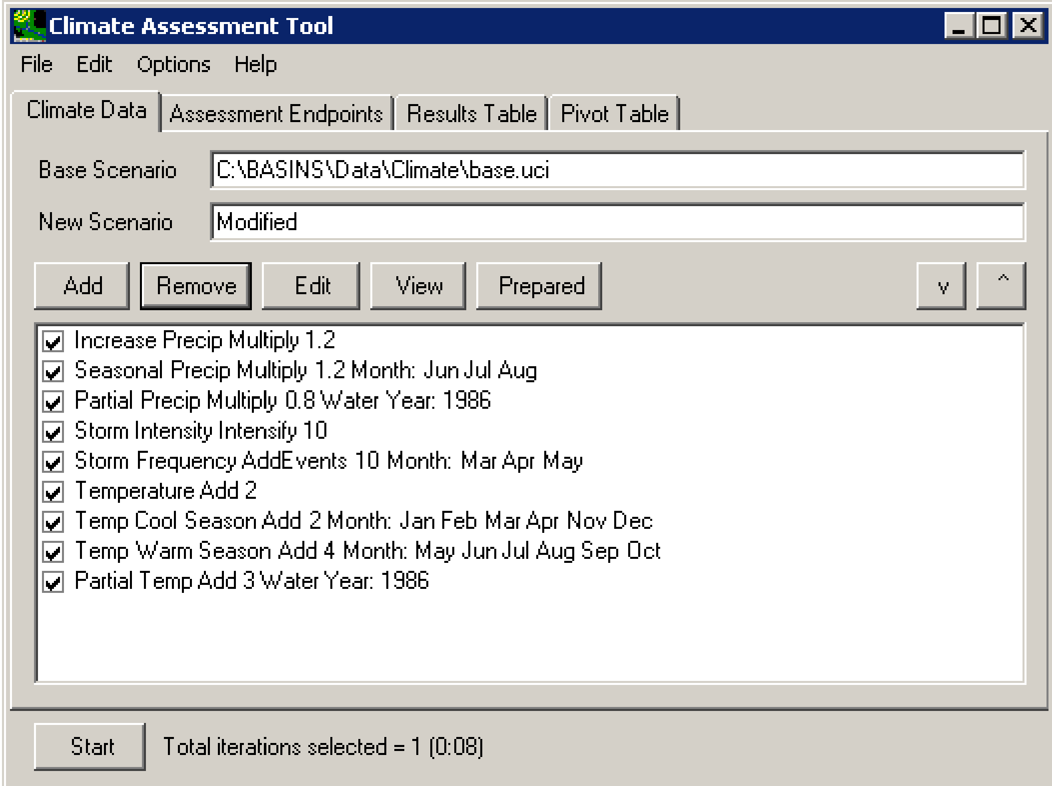


6. The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. Begin defining this subset by clicking on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. Items in the second field may be selected and deselected by

clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. The sample HSPF run used here is run for water years 1986 through 1988, with 1986 being the driest. Thus, to help assess the impact of drought, select the **Water Years** option and then select **1986** from the list of available water years.



7. Click the **Ok** button to complete the scenario definition process. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario.



8. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

3.1.3 Combine multiple changes to create a climate change scenario

This tutorial requires some number of climate adjustments to be defined using the tutorials in Sections 3.1.1.1 through 3.1.2.3. This tutorial uses climate adjustments defined in previous tutorials to show how they can be combined to create climate change scenarios composed of multiple adjustments to historical temperature and/or precipitation data. However, the tutorial can also be performed using climate adjustments other than those shown here.

This tutorial will create two climate change scenarios. The first combines temperature and precipitation changes to create a long term change scenario. The second combines decreasing precipitation and increasing temperature for a selected, single year to create a scenario representing the potential intensification of a drought year.

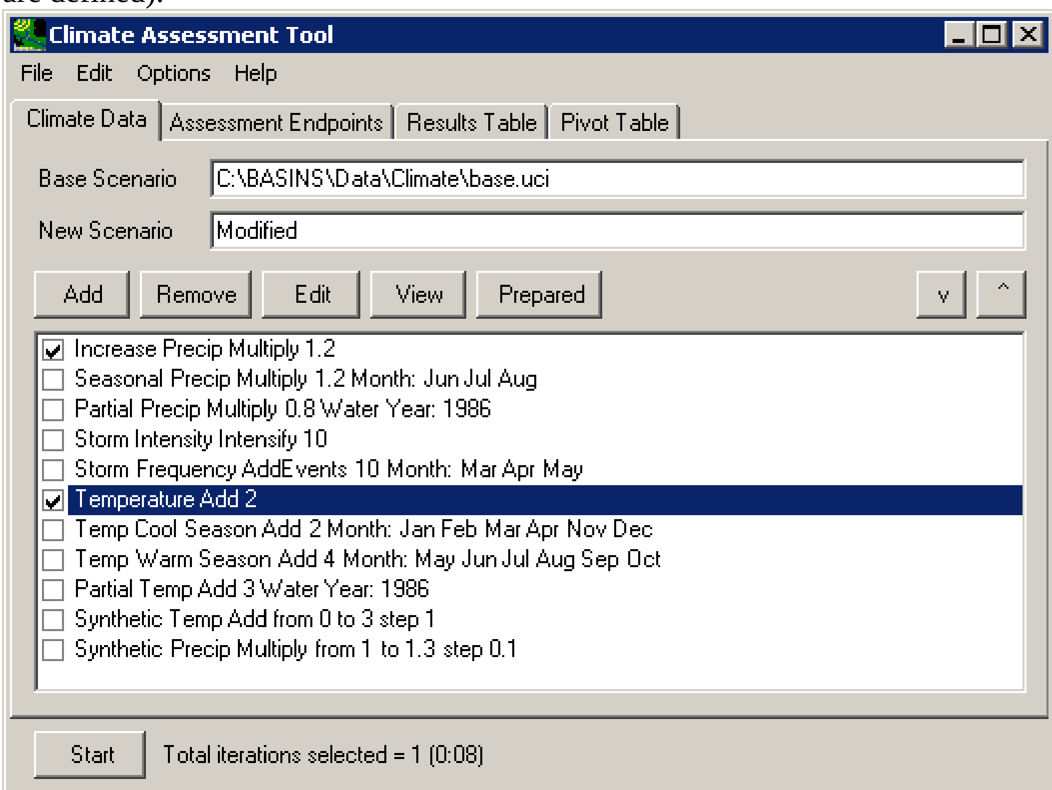
1. The **Climate Assessment Tool** form displays the previously defined climate adjustments in a list on the **Climate Data** tab. Each adjustment has a check box for indicating

whether or not it is to be included as a component of the climate scenario being developed. The order of adjustments may be controlled by selecting an adjustment and using the up and down arrow buttons above the list. This is particularly important when multiple adjustments are being made to the same values in an input data set (e.g. increasing an entire precipitation record and also increasing a season's storm intensity).

2. Begin defining a climate scenario by "checking on" the following adjustments:

- **Increase Precip Multiply 1.2**
- **Temperature Add 2**

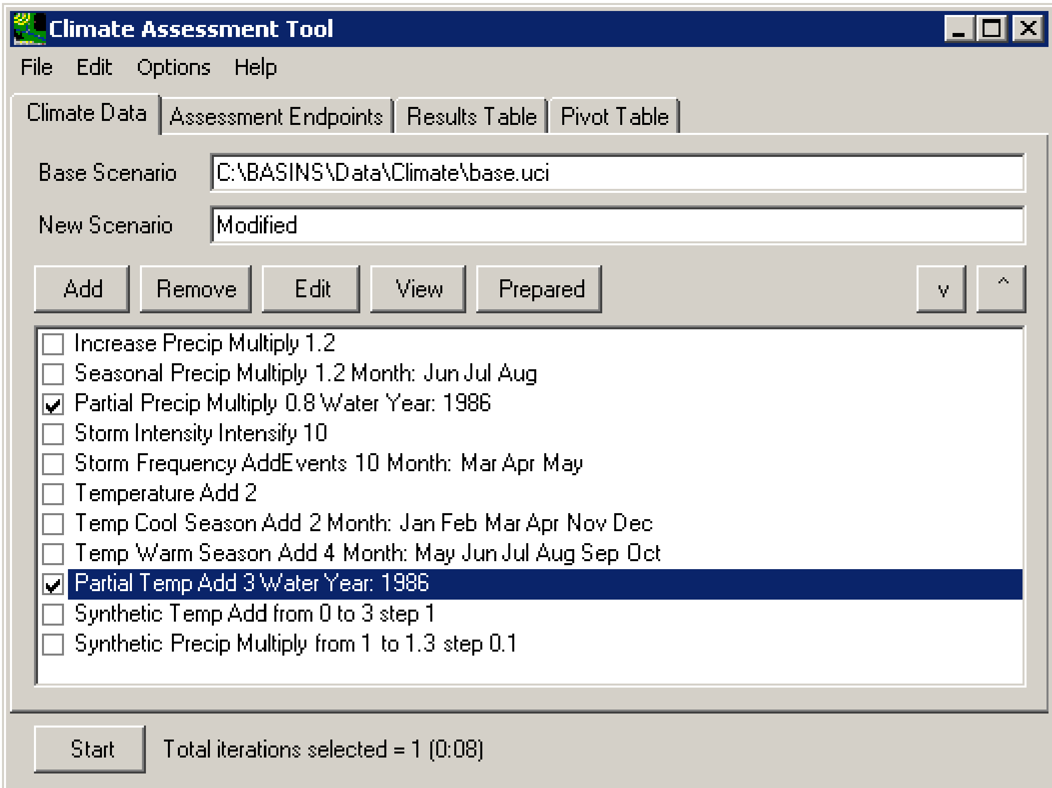
All other climate adjustments should be "checked off". This combination of adjustments represents a climate scenario that is available for input to the model. (Note: This scenario will not be run here as this tutorial is only demonstrating how climate change scenarios are defined).



3. Begin defining another scenario by "checking on" the following scenarios:

- **Partial Precip Multiply 0.8 Water Year: 1986**
- **Partial Temp Add 3 Water Year: 1986**

All other climate adjustments should be "checked off". This combination of adjustments represents a climate scenario for assessing the intensification of a drought year during a model run.



4. At the bottom of the CAT form, a label indicates the number of model runs (or **iterations**) that will be performed. For each climate scenario shown here, only one model run will be made. When a synthetic climate scenario (see the tutorial in Section 3.1.4) is used, a series of model runs is made to represent the iterations of the synthetic scenario. If multiple synthetic scenarios are used, a model run is made for each unique combination of adjustments defined by the scenarios. For example, a synthetic temperature scenario with four iterations combined with a synthetic temperature scenario with three iterations would result in twelve model runs.

3.1.4 Create Synthetic Climate Change Scenarios

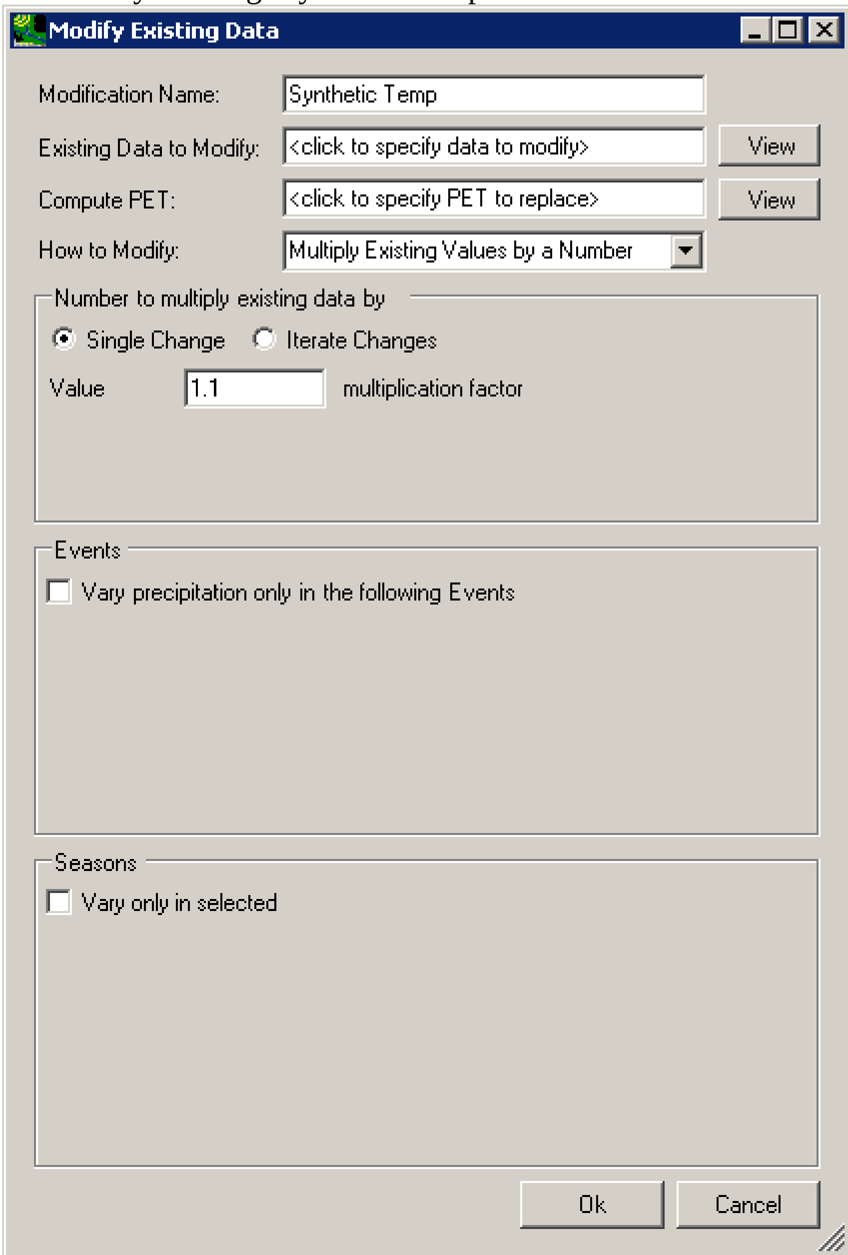
To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

CAT facilitates the creation of synthetic climate change scenarios by allowing for the specification of an iterative set of modifications to historical data. For background on how this feature may be used to represent climate change scenarios, see Section 2.3.1.4.

This tutorial will show how a series of multipliers may be applied to an entire historical precipitation data record to create synthetic climate change scenarios. The final result of the tutorial will be two synthetic scenarios - one that incrementally increases temperature values and one that incrementally increases precipitation values.

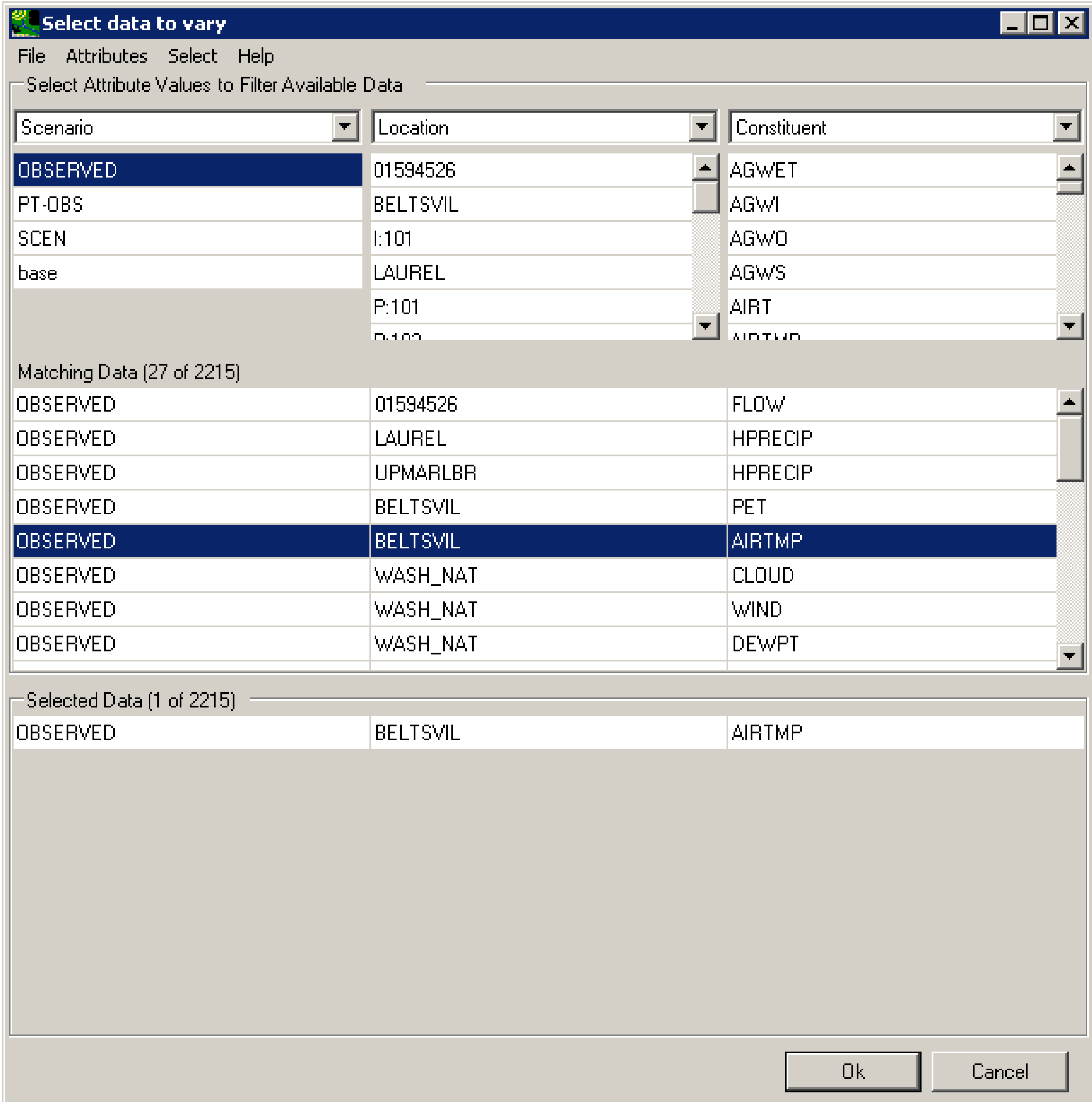
1. To begin creating the synthetic temperature scenario, click the **Add** button and the **Modify Existing Data** form will be displayed. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The **Modification Name** field is used to provide a text label for identifying the scenario being created. Begin defining this

scenario by entering 'Synthetic Temp' in the **Modification Name** field.

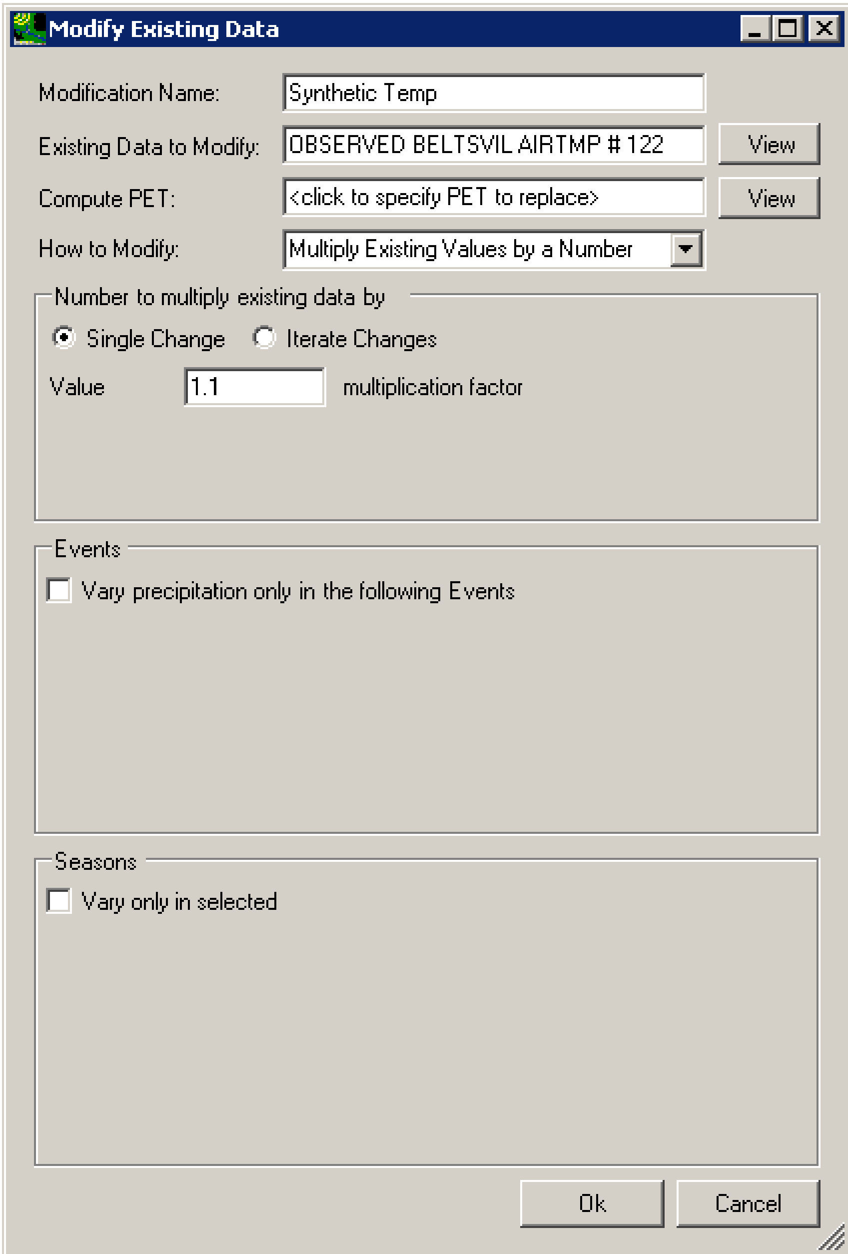


2. To select the air temperature data to modify, click in the **Existing Data to Modify** box and the **Select data to vary** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.2.1. In the first column, under the **Scenario** label, click on the **OBSERVED** item and all data sets with a Scenario attribute of OBSERVED will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note the data set with the **Constituent** name **AIRTMP** (air temperature). Click on this data set and it will be added to the **Selected Data** list. Click

the **Ok** button to close the form.

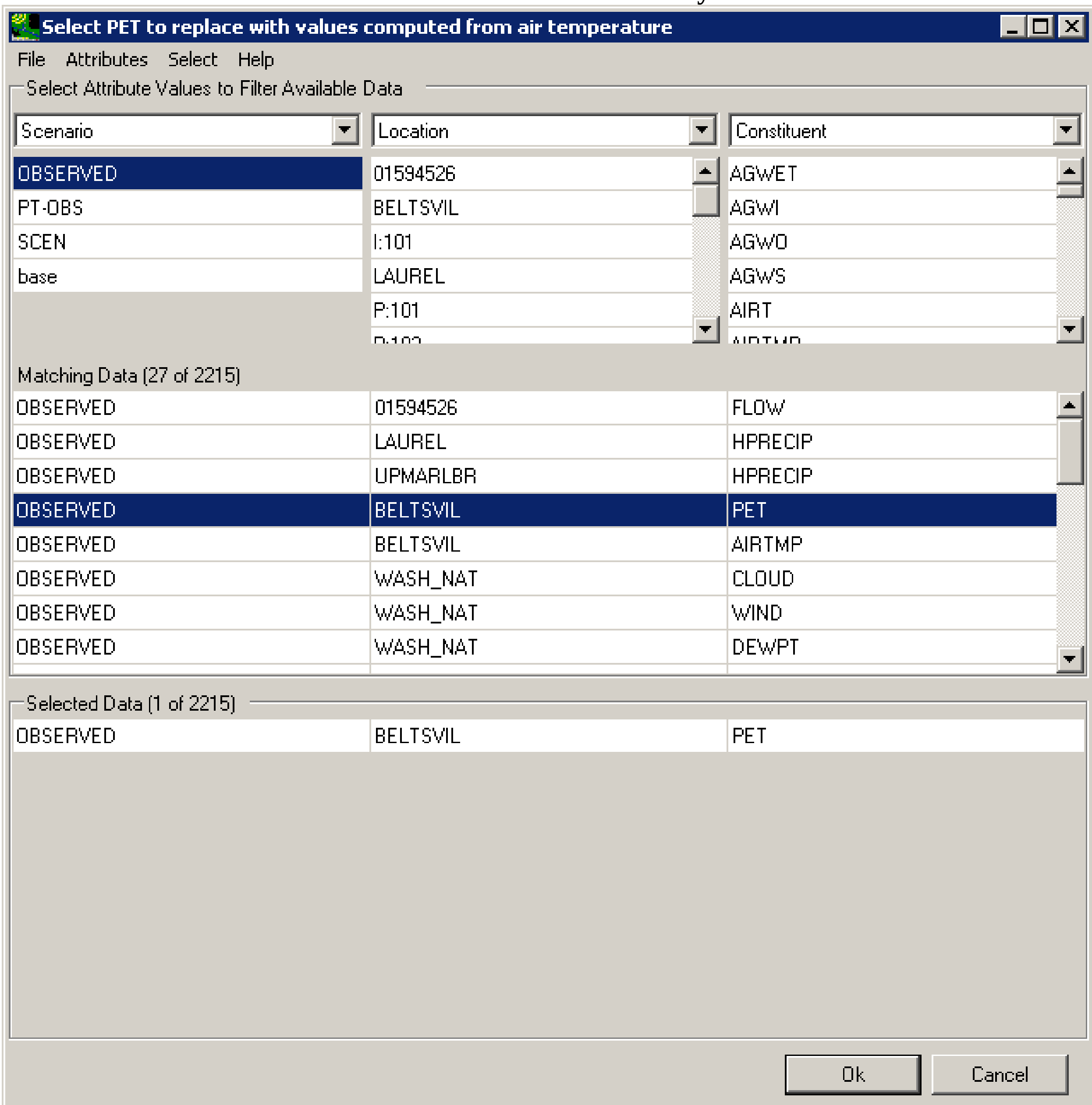


3. The **Modify Existing Data** form has now been updated with a description of the selected data set in the **Existing Data to Modify** box. When modifying temperature it is necessary to also re-compute the Potential Evapotranspiration (PET) using the modified temperature data. Click in the **Compute PET** box to specify which PET data to re-compute.



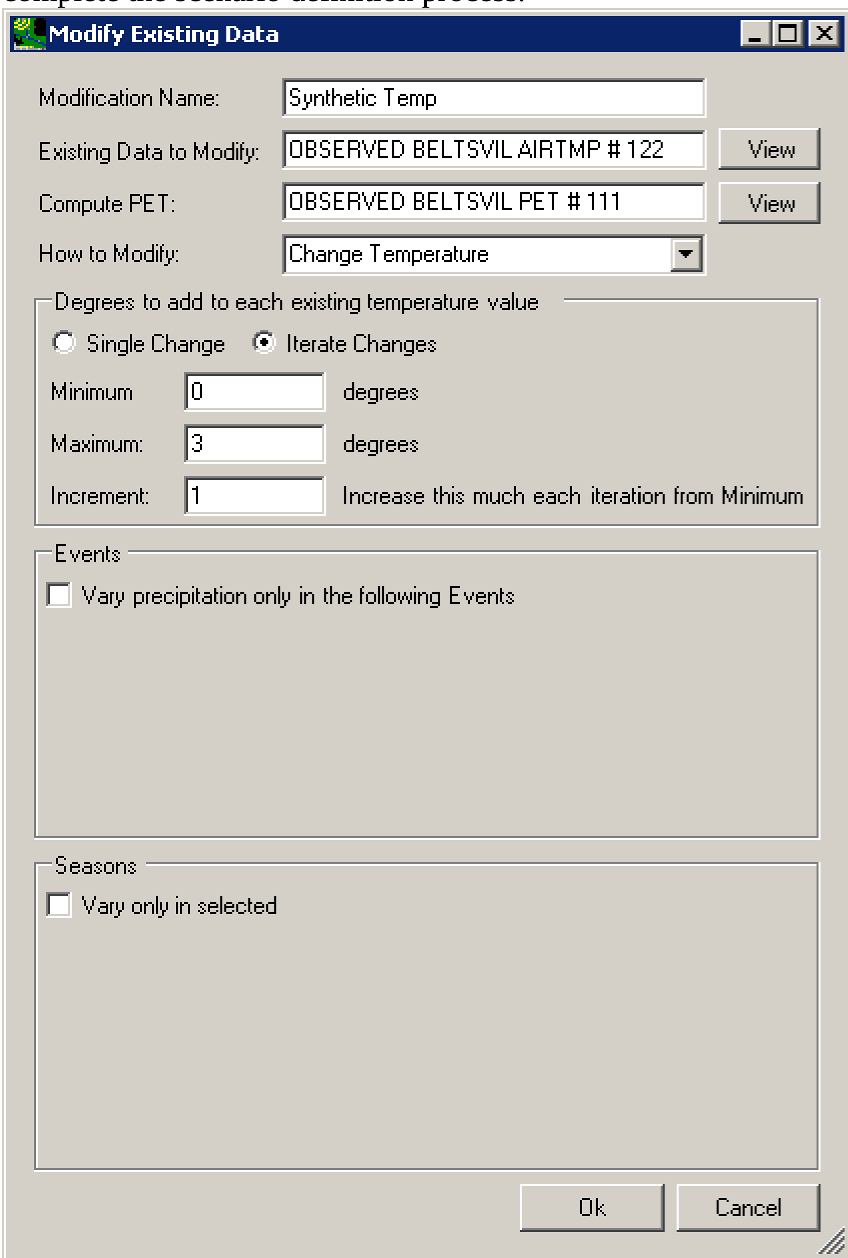
4. In the **Select data to vary** form, again click on the **OBSERVED** item in the **Scenario** column and then click the **OBSERVED BELTSVIL PET** data set from the **Matching**

Data list. Click the **Ok** button to close the **Select data to vary** form.

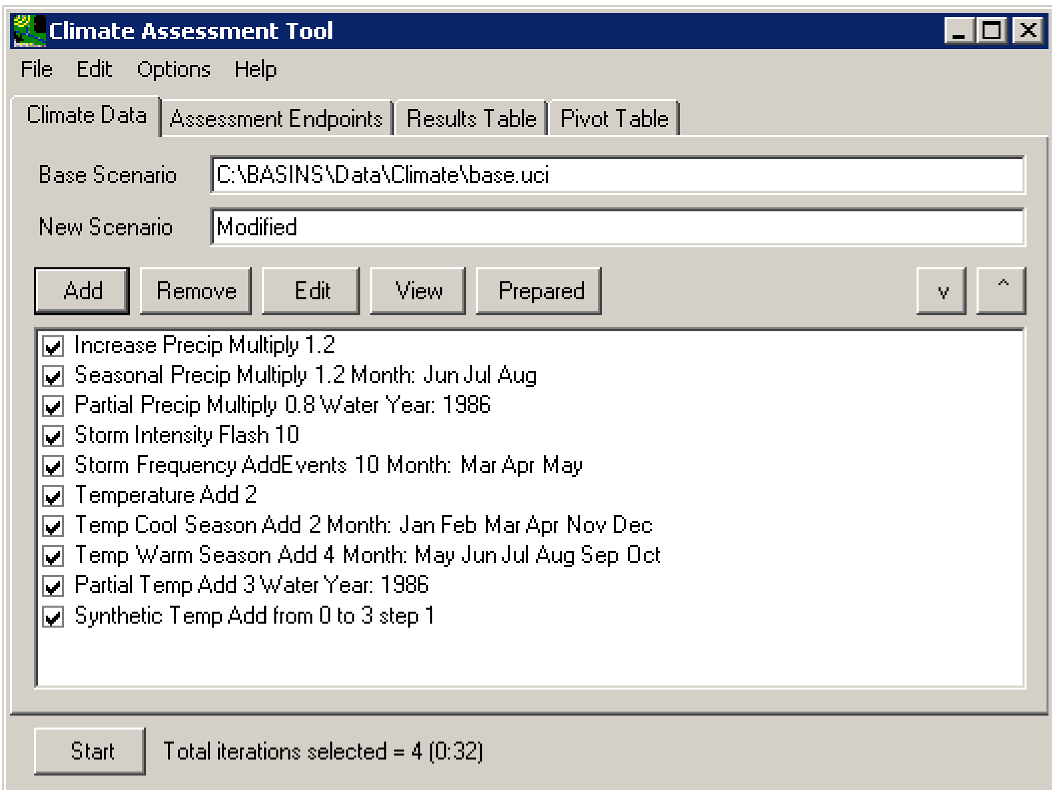


5. The **Modify Existing Data** form has been updated with a description of the selected data set in the **Compute PET** box. The **How to Modify** box contains a list of methods for modifying the data-set values. For this scenario, select the "Change Temperature" option. In the **Degrees to add to each existing temperature value** frame, there are two modification options: **Single Change** or **Iterate Changes**. The term 'iterate' as used here refers to the automation of multiple runs. The **Single Change** option will result in one adjustment applied to the temperature and PET data sets. The **Iterate Changes** option will result in a series of adjustments to the temperature and PET data sets and is

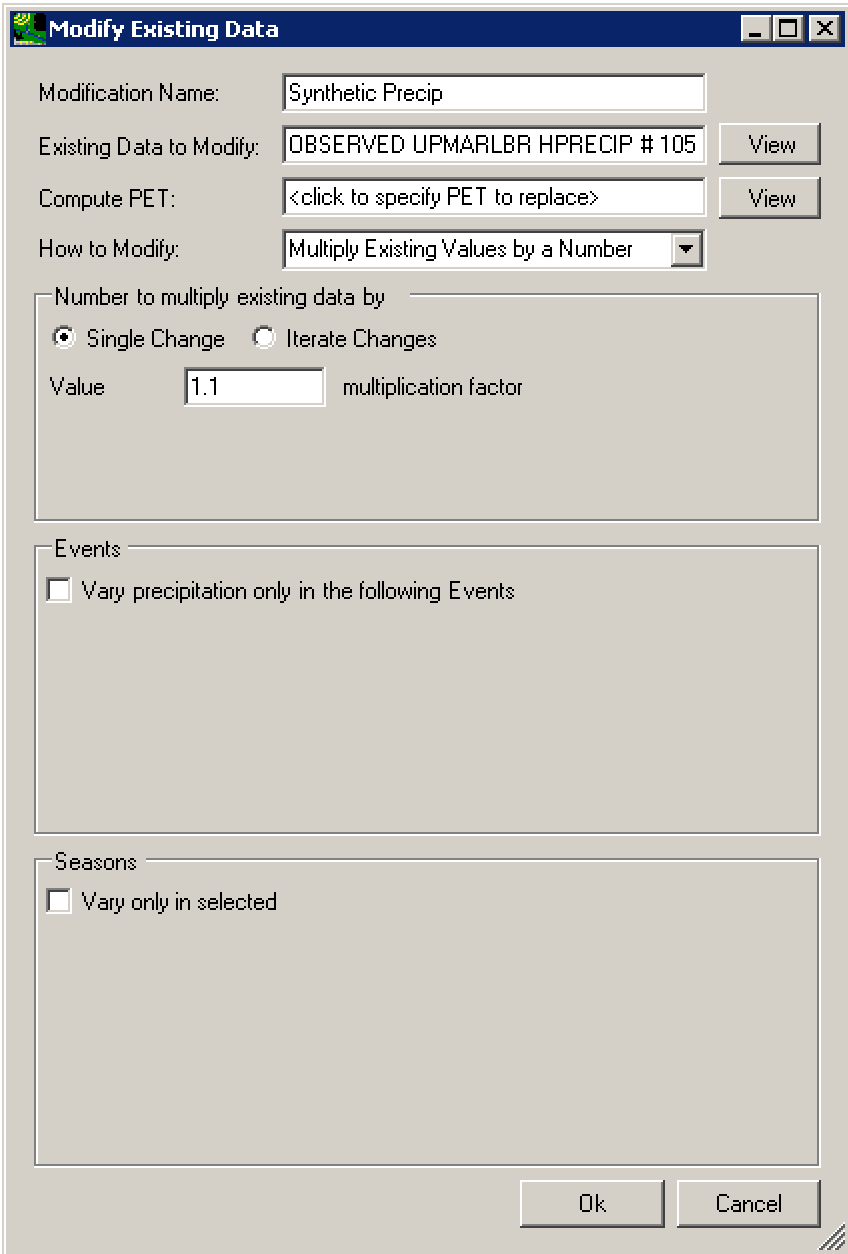
used to create "synthetic" climate change scenarios as defined in Section 2.3.1.4. Click the **Iterate Changes** radio button and the form will be updated to allow entry of **Minimum** and **Maximum** degree changes along with an **Increment** to apply over that range. Enter a **Minimum** value of '0', a **Maximum** value of '3', and an **Increment** value of '1'. This will create a synthetic scenario with four iterations, the first being identical to the original data and the ensuing three having 1 additional degree added to historical temperature data with PET data being computed from each. Click the **Ok** button to complete the scenario definition process.



6. The **Climate Assessment Tool** form is now updated to show the newly defined climate scenario. To begin defining the synthetic precipitation scenario, click the **Add** button again.

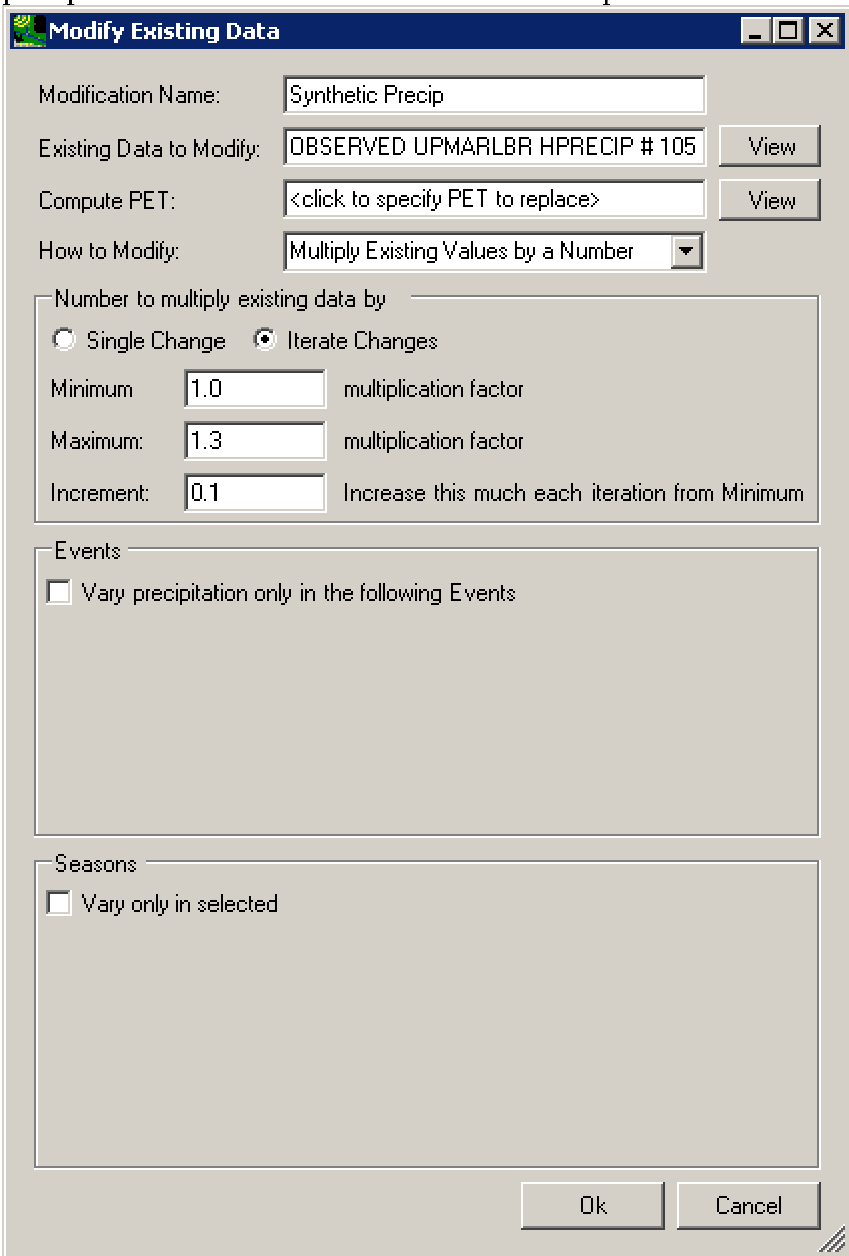


7. From the **Modify Existing Data** form, enter ‘Synthetic Precip’ in the **Modification Name** field. Next, click in the **Existing Data to Modify** box to select the precipitation data set to be modified. As in step 2, from the **Select data to vary** form click the **OBSERVED** item from the **Scenario** list. From the **Matching Data** list, click on the data set with the attributes **OBSERVED UPMARLBR HPRECIP** and then click the **Ok**. The **Modify Existing Data** form will be updated to show the selected precipitation data set.

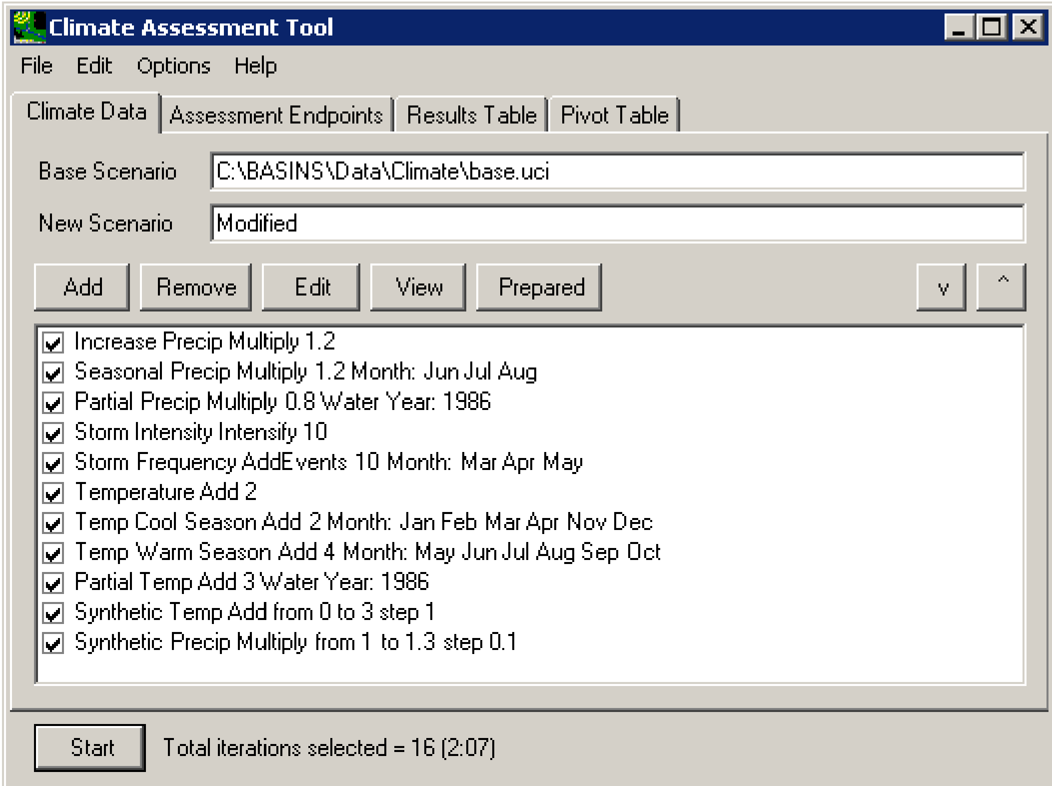


8. For the synthetic precipitation scenario, select **Multiply Existing Values by a Number** from the **How to Modify** list. As with the synthetic temperature scenario, click on the **Iterate Changes** option in the **Number to multiply existing data by** frame. Enter a **Minimum** value of '1.0', a **Maximum** value of '1.3', and an **Increment** value of '0.1'. This will create a synthetic scenario with four iterations, the first being identical to the original data and the ensuing three having 1/10 additional volume added to the historical

precipitation data. Click the **Ok** button to complete the scenario definition process.



9. Click the **Ok** button to complete defining the synthetic precipitation scenario. The newly defined scenario will be shown on the **Climate Assessment Tool** form.



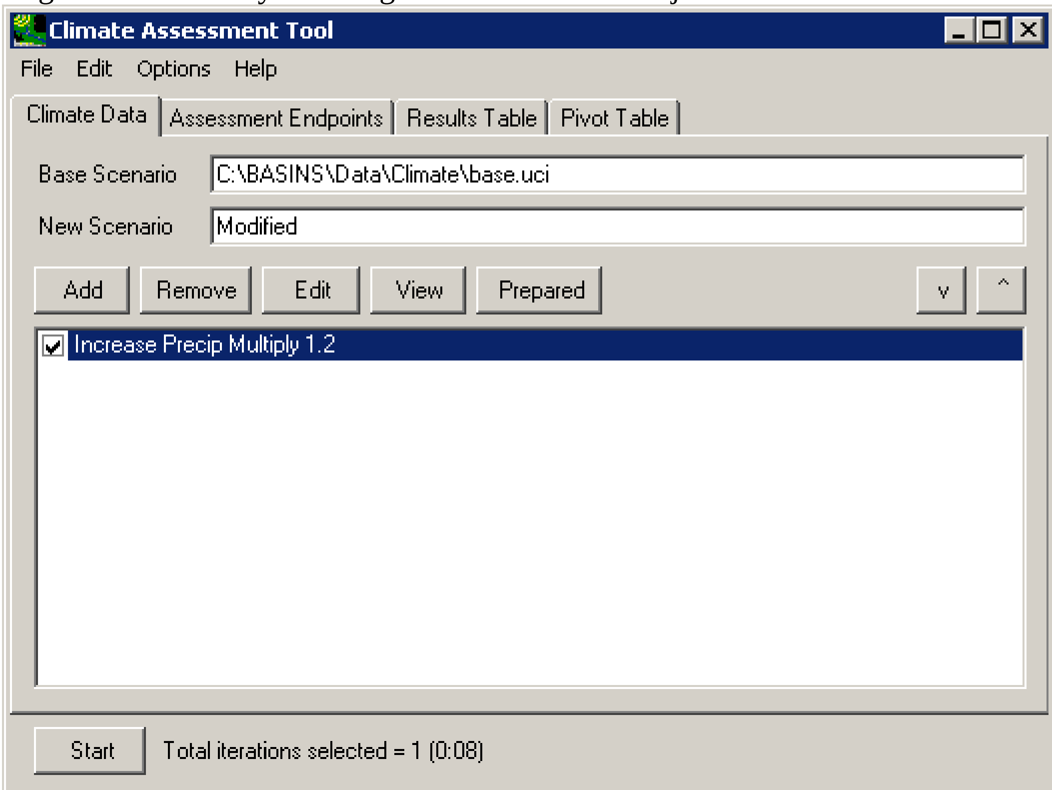
10. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

Exporting Climate Change Scenarios as ASCII Text Files

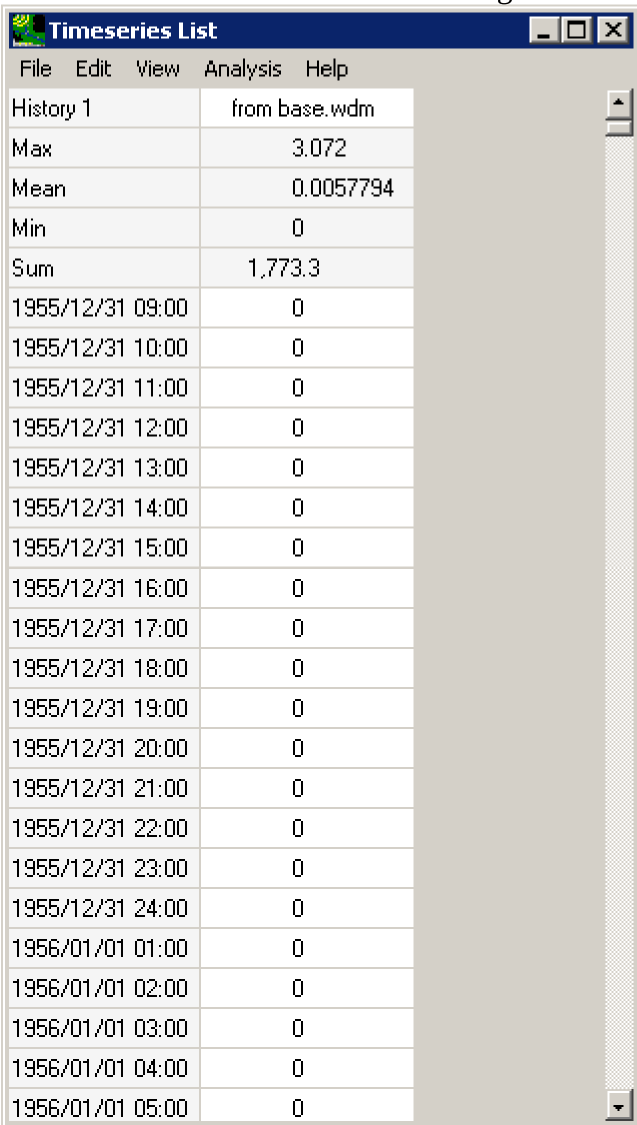
This tutorial requires the development of at least one climate adjustment. This can be either a precipitation (Sections 3.1.1.1 - 3.1.1.5) or temperature (Sections 3.1.2.1 - 3.1.2.3) adjustment (or both). This tutorial uses a specific adjustment as an example, but the exporting feature shown here can be applied to any defined adjustment.

This tutorial will demonstrate how climate adjustments defined in CAT can be exported to a file for use elsewhere. Individual adjustments to a historical record may be viewed and saved from the **Climate Data** tab. That feature is demonstrated in this tutorial. If multiple adjustments are applied to the same data record, the resulting data set incorporating all of the adjustments is not available for viewing and saving until the model run has been made. Accessing this type of modified data is shown in Section 3.4.4 Additional BASINS Tools.

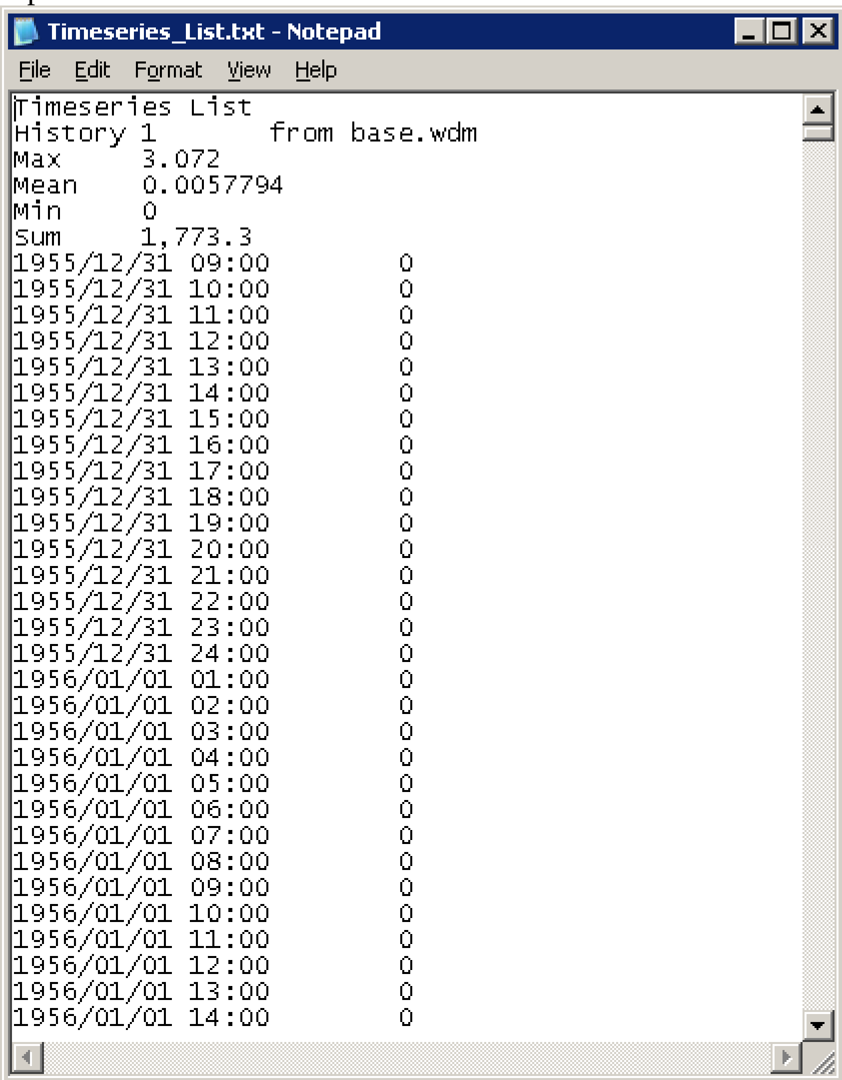
Begin this tutorial by selecting one of the climate adjustments shown on the **Climate Data** tab.



Next click the **View** button and a listing of the data set being modified will be displayed.



From the **Time series List** form, select the **File:Save** menu option and a file dialogue form will allow you to specify the file to which the listing is to be saved. The values will be saved in a tab-separated format as shown below.



```
Timeseries List
History 1        from base.wdm
Max      3.072
Mean     0.0057794
Min      0
Sum      1,773.3
1955/12/31 09:00        0
1955/12/31 10:00        0
1955/12/31 11:00        0
1955/12/31 12:00        0
1955/12/31 13:00        0
1955/12/31 14:00        0
1955/12/31 15:00        0
1955/12/31 16:00        0
1955/12/31 17:00        0
1955/12/31 18:00        0
1955/12/31 19:00        0
1955/12/31 20:00        0
1955/12/31 21:00        0
1955/12/31 22:00        0
1955/12/31 23:00        0
1955/12/31 24:00        0
1956/01/01 01:00        0
1956/01/01 02:00        0
1956/01/01 03:00        0
1956/01/01 04:00        0
1956/01/01 05:00        0
1956/01/01 06:00        0
1956/01/01 07:00        0
1956/01/01 08:00        0
1956/01/01 09:00        0
1956/01/01 10:00        0
1956/01/01 11:00        0
1956/01/01 12:00        0
1956/01/01 13:00        0
1956/01/01 14:00        0
```

To end this session, close the **Time series List** form.

3.2 Tools for Assessing Environmental Endpoints

BASINS CAT provides a post-processing capability to calculate hydrologic and water quality endpoints from HSPF output time series. As described in Chapter 2, endpoints may range from simple (e.g. mean streamflow, annual sediment load) to complex (e.g. n-day frequency flow values).

The tutorials in this section illustrate how to:

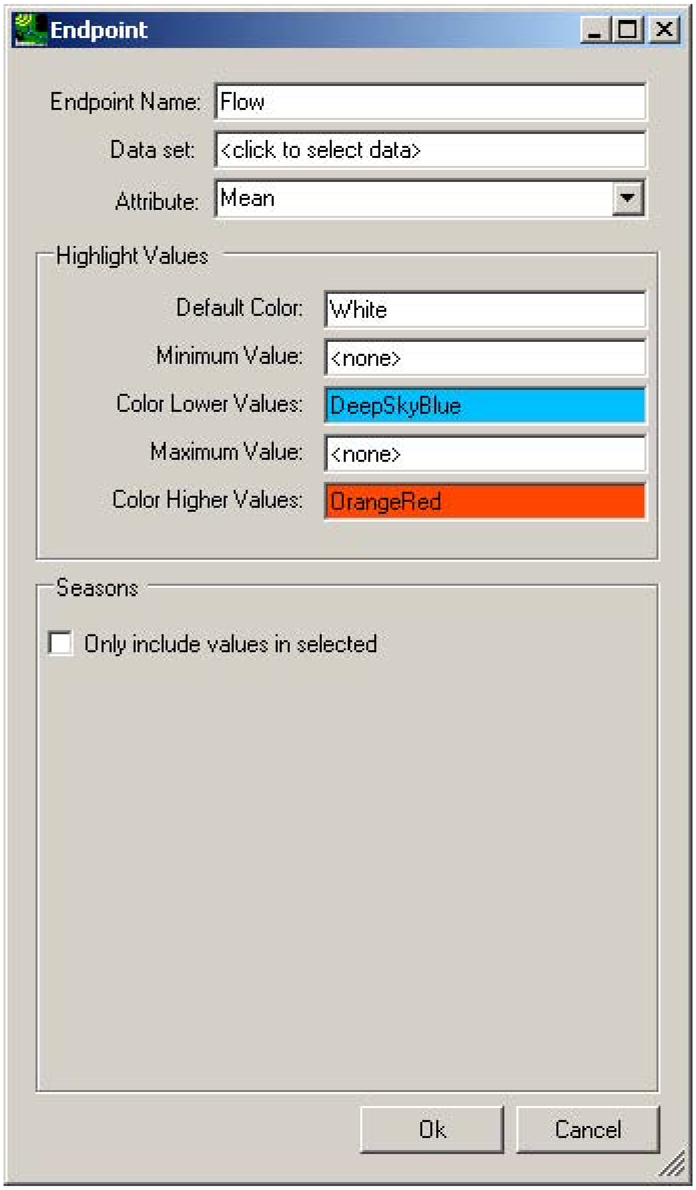
- Select endpoints to be calculated from HSPF output time series
- Specify value ranges of concern
- Specify time periods of concern

3.2.1 Endpoint Options

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

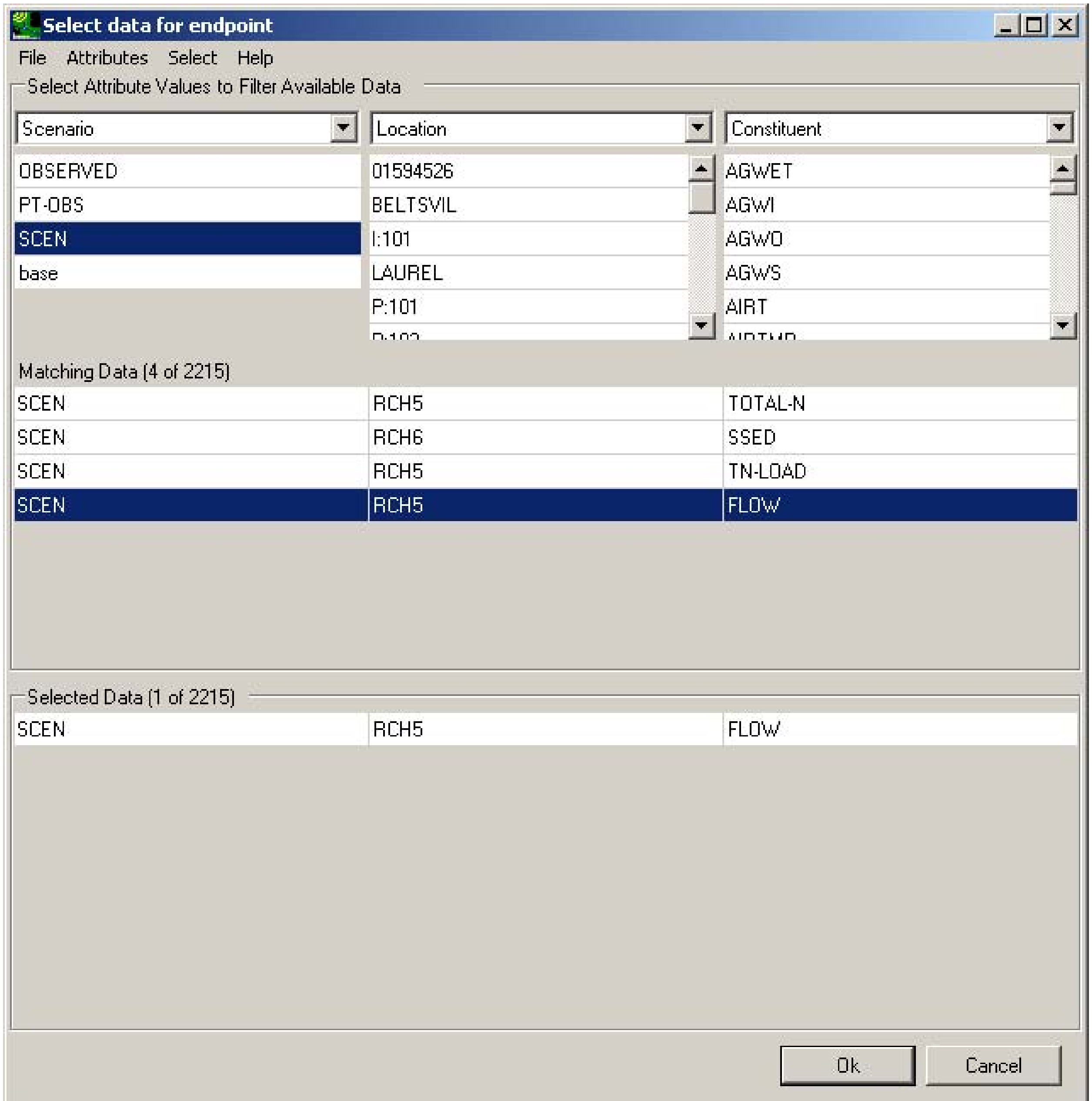
After defining and selecting the input climate modifications to be used, the next phase of a CAT analysis is the definition of assessment endpoints. This tutorial will demonstrate the basic functionality of assessment endpoint specification. The final result of this tutorial will be the definition of two assessment endpoints: one for flow and one for total nitrogen loading.

1. The defining of endpoints is performed through the **Assessment Endpoints** tab on the CAT form. After clicking on this tab, begin defining a new endpoint by clicking on the **Add** button. The form contains the controls needed to define an assessment endpoint, including the endpoint name, the dataset to be analyzed, and the attribute of the dataset to be reported. The **Endpoint Name** field is used to provide a text label for identifying the assessment endpoint being created. Begin defining this endpoint by entering 'Flow' in the **Endpoint Name** field.

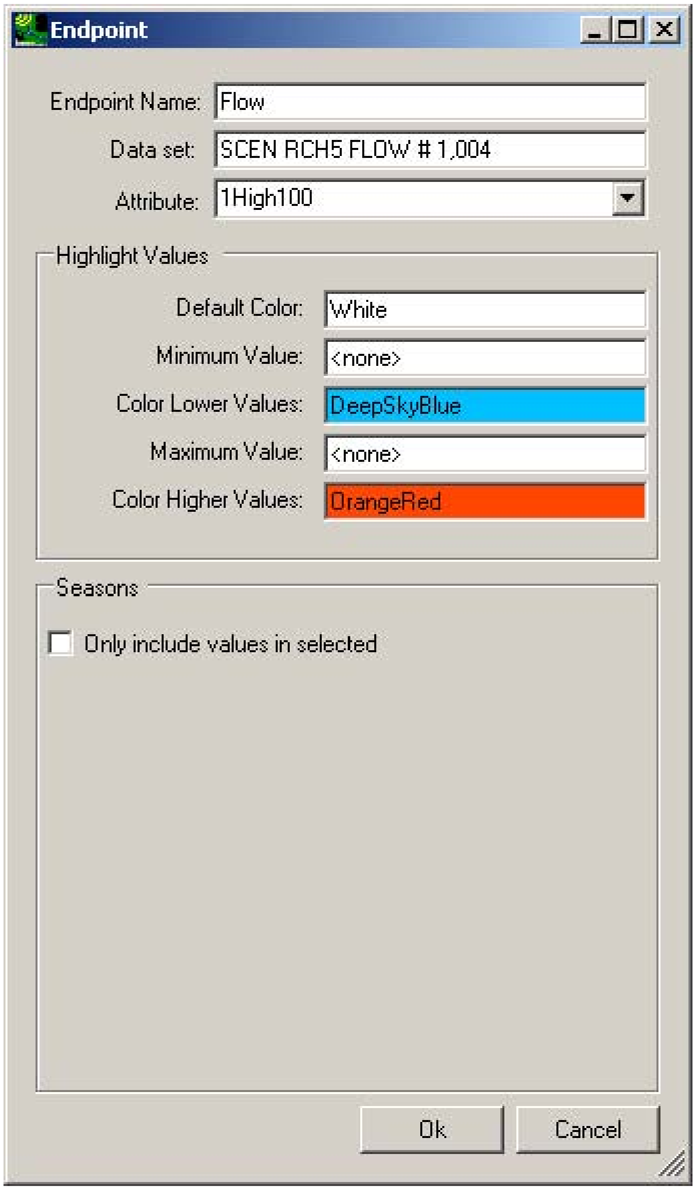


2. Begin defining the data for the endpoint by clicking in the **Data set** box and the **Select data for endpoint** form will be displayed. A detailed description of this form is found in steps 2 and 3 of the tutorial in Section 3.1.2.1. In the first column, under the **Scenario** label, click on the **SCEN** item and all data sets with a Scenario attribute of SCEN will be added to the **Matching Data** list. In looking at the last column of the **Matching Data** list, note the data set with the **Constituent** name **FLOW**. Click on this data set and it

will be added to the **Selected Data** list. Click the **Ok** button to close the form.

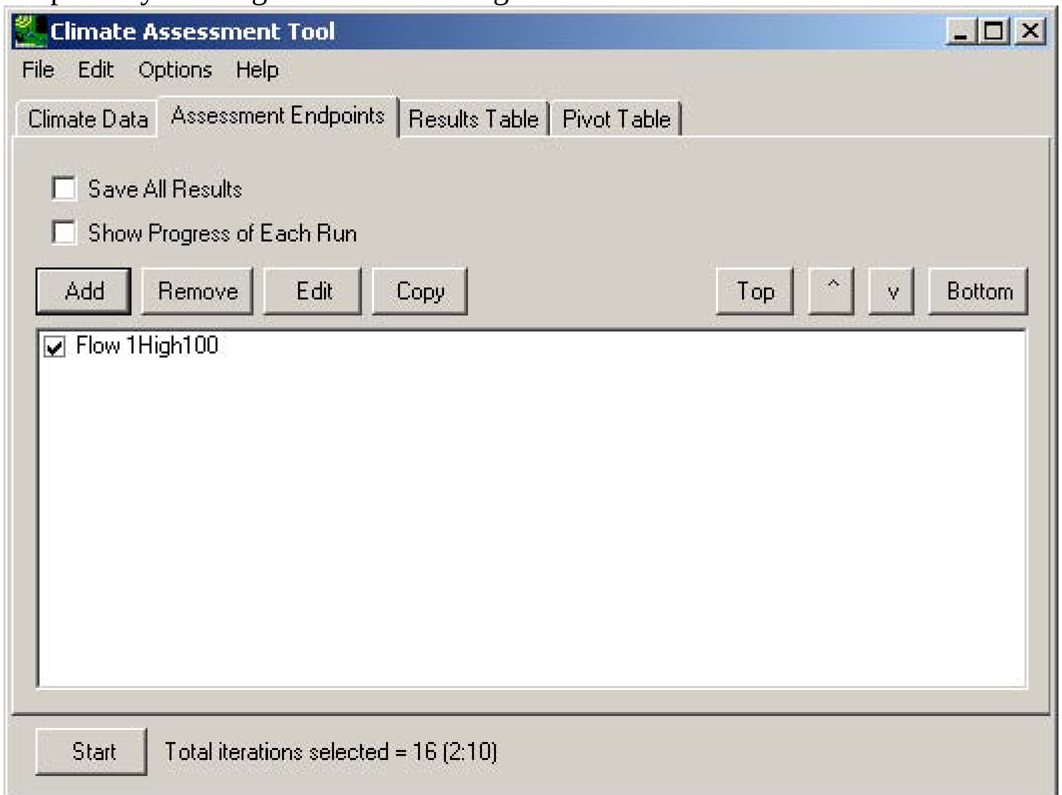


3. The **Endpoint** form has now been updated with a description of the selected Flow data in the **Data set** box. The **Attribute** pull-down list contains the attributes available for selection as assessment endpoints. CAT provides a wide array of attributes, from standard statistics (e.g. mean, sum, standard deviation) to duration-frequency statistics (e.g. 7Q10, 100-year flood). For this example, we will specify an endpoint focused on high flow, so select the **1Hi100** (i.e. 1-day Hi value occurring every 100 years or 100 year flood) item from the list.



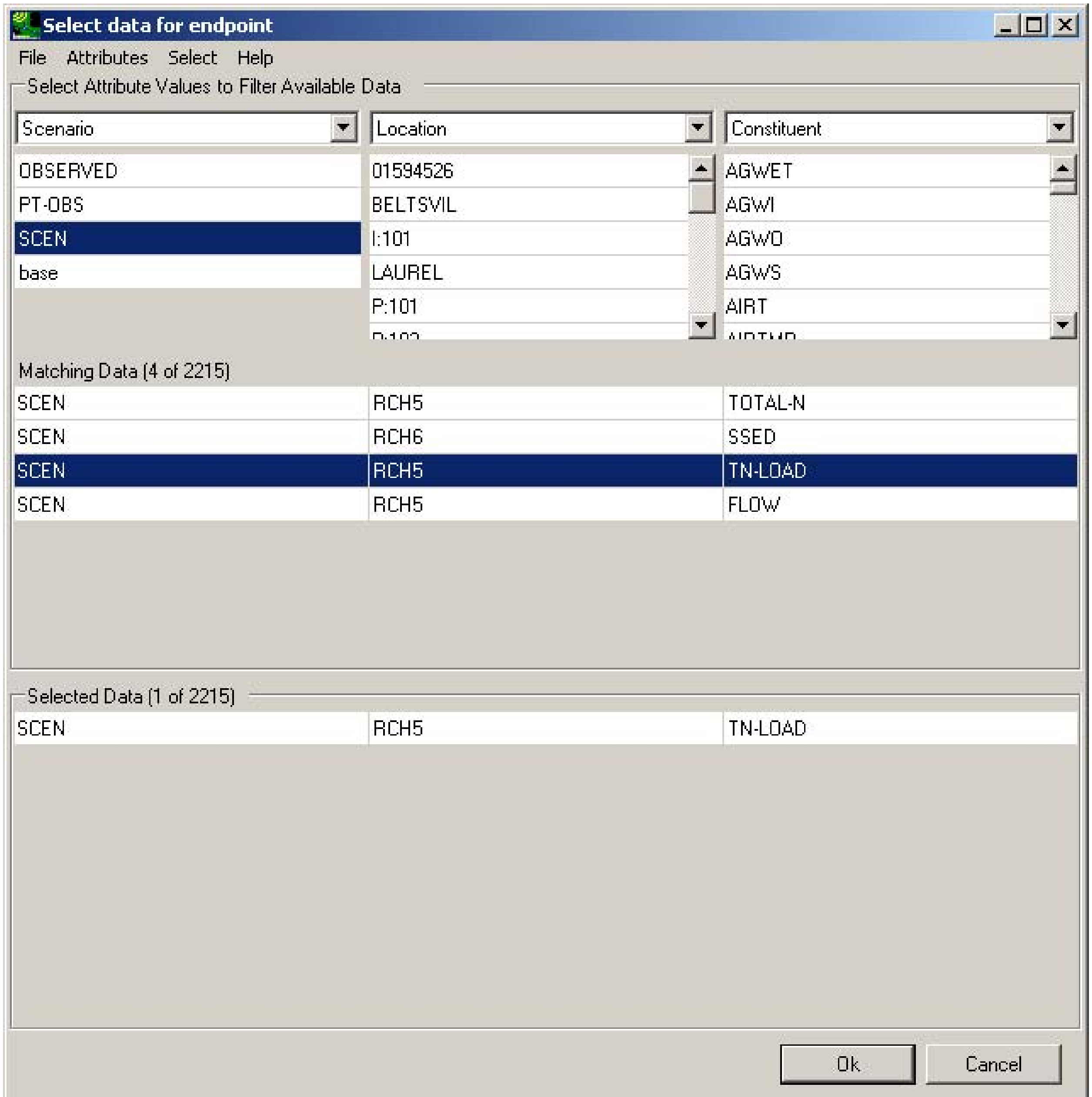
4. Click the **Ok** button to complete defining this endpoint. The **Climate Assessment Tool** form will be updated to show the newly defined end point. Begin defining a second

endpoint by clicking the **Add** button again.

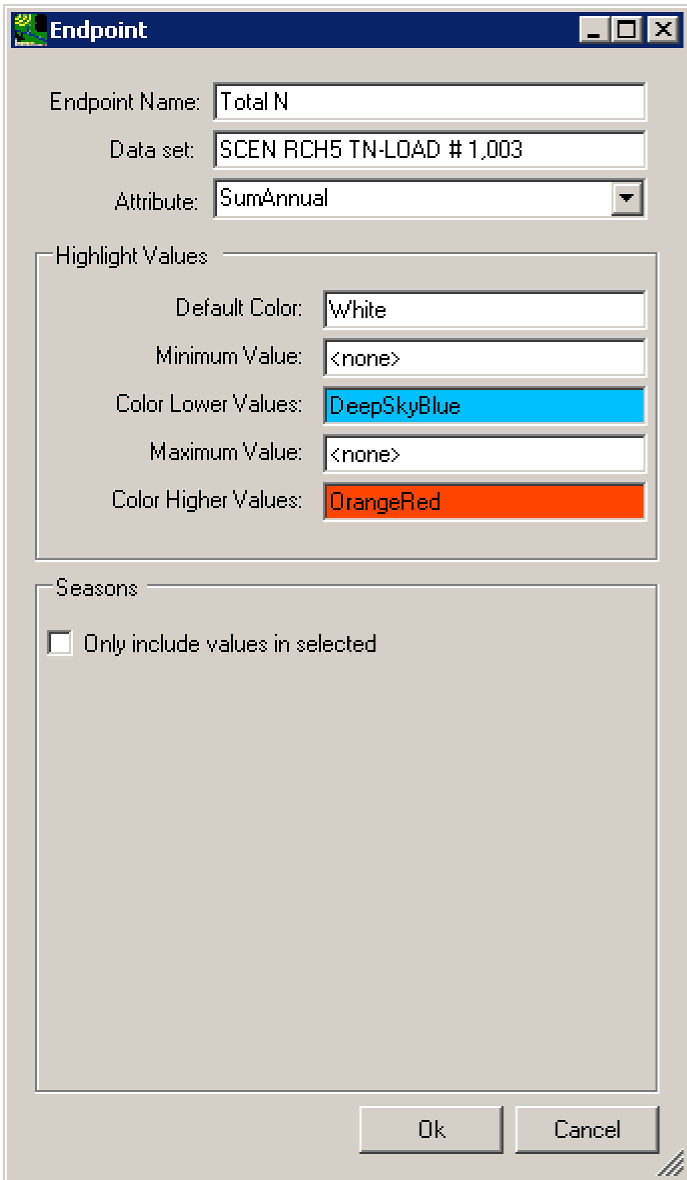


5. Now we will define an assessment endpoint for total Nitrogen load. Begin by entering ‘Total N’ in the **Endpoint Name** field and then click in the **Data set** box to select the appropriate data set. On the **Select data for endpoint** form, again click the **SCEN** item in the **Scenario** list. From the **Matching Data** list, click on the data set with a

constituent name of **TN-LOAD**. Click the **Ok** button to close the form.

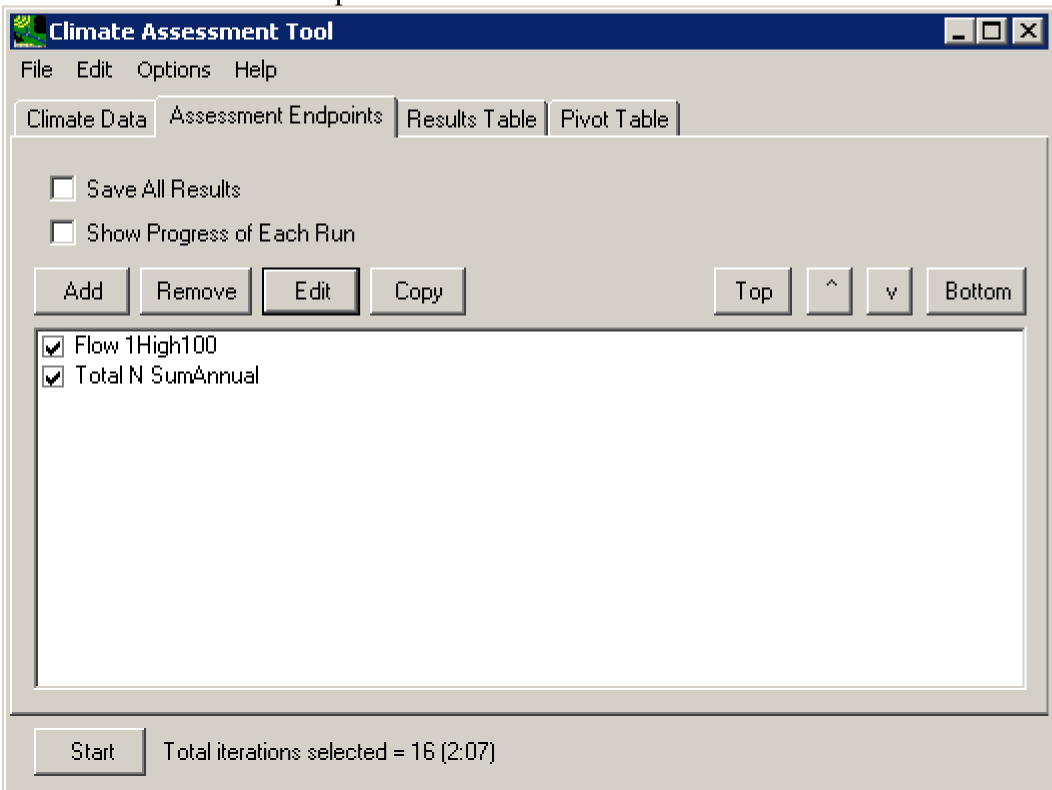


6. The **Endpoint** form has now been updated with a description of the selected Flow data in the **Data set** box. As opposed to the previous extreme event selected for the flow endpoint, this endpoint will look to assess annual values. Thus in the **Attribute** list, select the **SumAnnual** item, resulting in an endpoint that reports average annual loads of total Nitrogen.


Endpoint
Endpoint Name:
Total N
Data set:
SCEN RCH5 TN-LOAD # 1,003
Attribute:
SumAnnual
Highlight Values
Default Color:
White
Minimum Value:
<none>
Color Lower Values:
DeepSkyBlue
Maximum Value:
<none>
Color Higher Values:
OrangeRed
Seasons
Only include values in selected
Ok
Cancel

1

7. Click the **Ok** button to complete defining this endpoint. The **Climate Assessment Tool** form now shows both endpoints defined in this session.



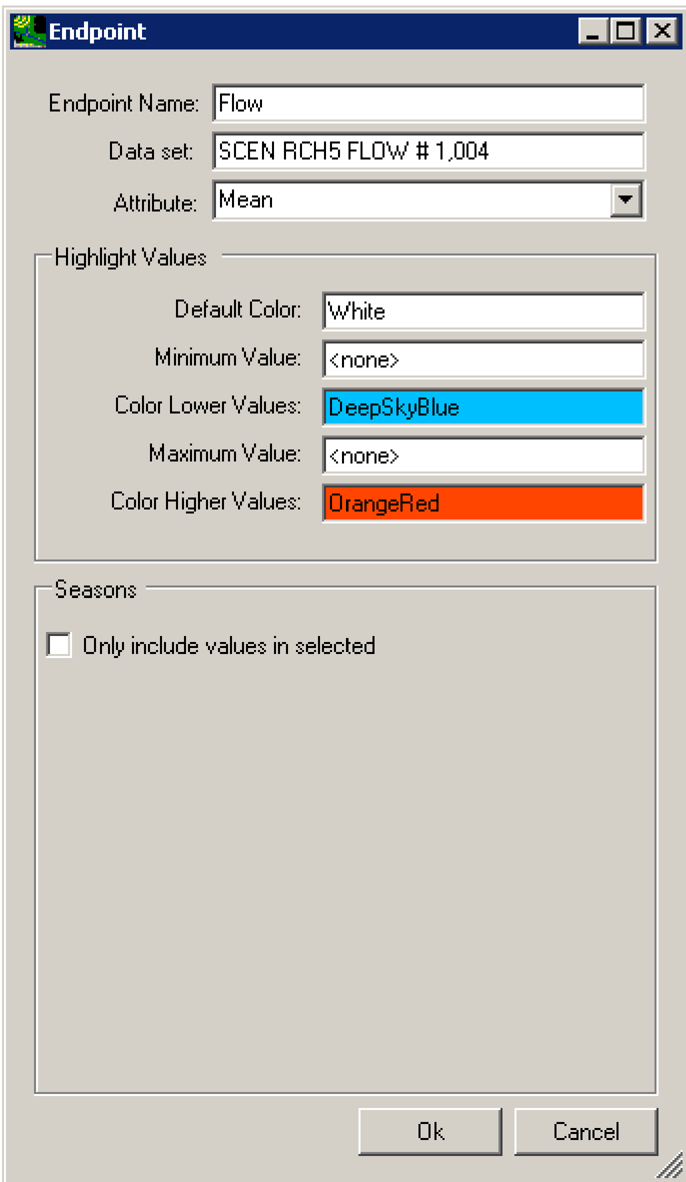
8. To complete this session, save the state of CAT, using the File:Save Climate and Endpoints menu option, if desired.

3.2.2 Specify Value Ranges of Concern

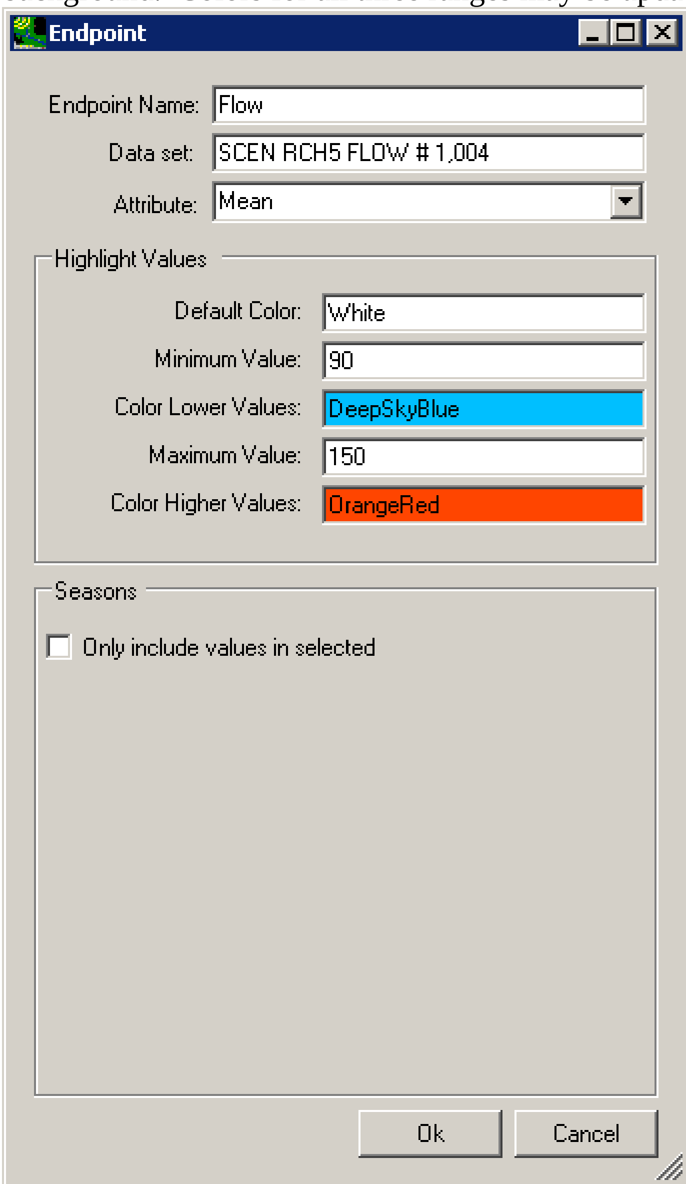
To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

BASINS CAT provides a capability to specify ranges of concern for endpoint values. Critically low and/or high values may be entered, along with indicator colors, during endpoint definition. Endpoint values that fall outside of the specified critical range will then be highlighted in the specified indicator color on the results display. This tutorial will demonstrate how to specify value ranges of concern when selecting endpoints.

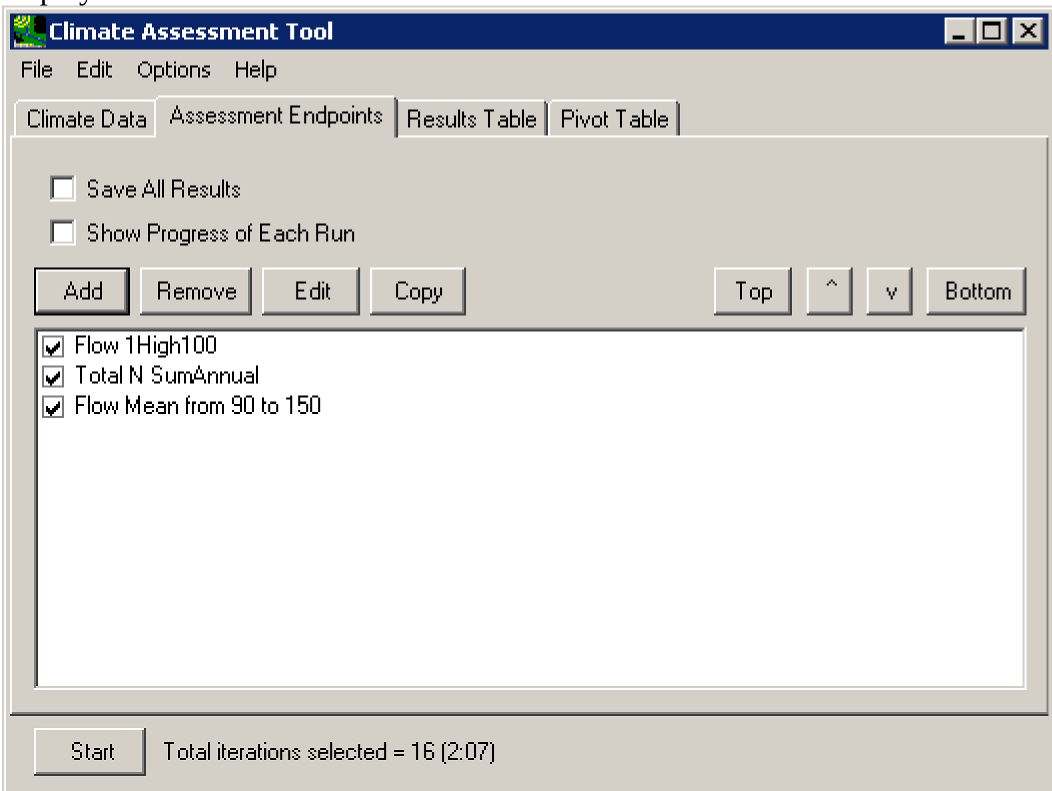
1. The defining of endpoints is performed through the **Assessment Endpoints** tab on the CAT form. After clicking on this tab, begin defining a new endpoint by clicking on the **Add** button. The form contains the controls needed to define an assessment endpoint, including the endpoint name, the data set to be analyzed, and the attribute of the dataset to be reported. Details of how to define these elements are found in steps 1 through 3 of the Endpoint Options tutorial in Section 3.2.1. Begin defining this endpoint by entering ‘Flow’ in the **Endpoint Name** field. Click in the **Data set** box to select the data set to be analyzed. Select the data set with the attributes **SCEN RCH5 FLOW** from the **Select data for endpoints** form. Leave the **Attribute** field as the default of **Mean**. The form should now appear as below.



2. The highlight feature in CAT is provided as an aid to visually interpreting model output. Specifications for this feature are found in the **Highlight Values** frame. In this example, we wish to highlight values falling outside of the range from 90 to 150 cfs. Type in ‘90’ for the **Minimum Value** and ‘150’ for the **Maximum Value**. Results within the specified range will be displayed in cells with the **Default Color** background. Results below the **Minimum Value** will be displayed with the **Color Lower Values** background. Results above the **Maximum Value** will be displayed with the **Color Higher Values** background. Colors for all three ranges may be updated by clicking in the **color** fields.



3. Click the **Ok** to complete defining of this endpoint. The new created endpoint will be displayed on the **Climate Assessment Tool** form.



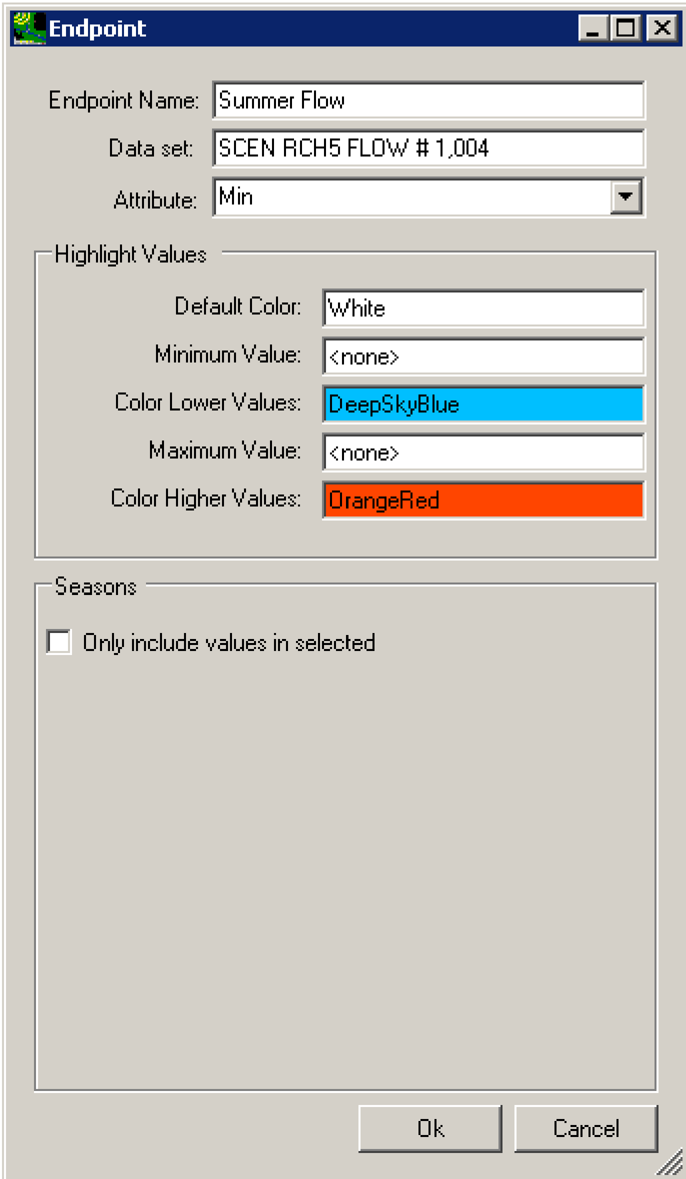
3.2.3 Specify Time Periods of Concern (Seasonal and/or Partial Records)

To begin this tutorial, the **Climate Assessment Tool** form should be displayed with the "\Basins\Data\Climate\base.uci" file as the **Base Scenario**, "Modified" as the **New Scenario**, and the "\Basins\Data\Climate\base.wdm" file added to the BASINS project. These specifications are performed in the BASINS-CAT Setup tutorial in Section 3.0, which must be run prior to this tutorial.

A specialized feature of CAT assessment endpoints is the ability to specify a subset of time for computation of the endpoint values. This subset may be a select set of months for each year of the model run or a selected year (or years) from the run. Endpoint values will then be computed from only those time intervals that fall within the specified subset. This tutorial will demonstrate how to specify date subsets when defining endpoints.

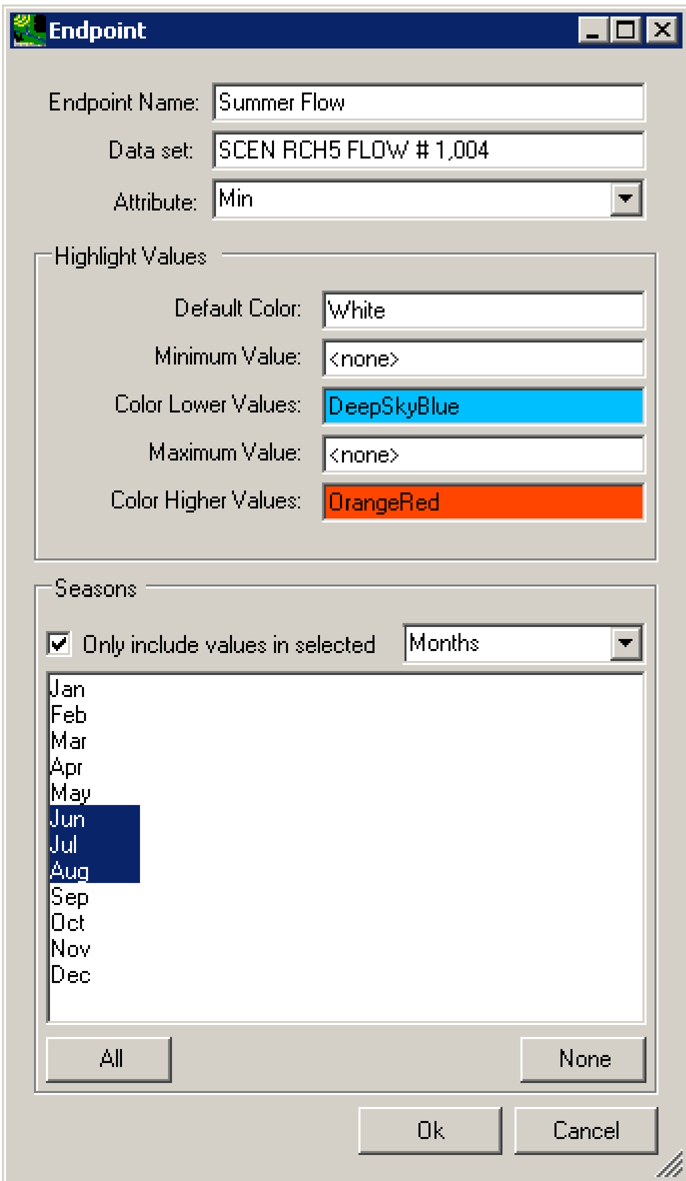
1. The defining of endpoints is performed through the **Assessment Endpoints** tab on the CAT form. After clicking on this tab, begin defining a new endpoint by clicking on the **Add** button. The form contains the controls needed to define an assessment endpoint, including the endpoint name, the data set to be analyzed, and the attribute of the dataset

to be reported. Details of how to define these elements are found in steps 1 through 3 of the Endpoint Options tutorial in Section 3.2.1. Begin defining this endpoint by entering ‘Summer Flow’ in the **Endpoint Name** field. Click in the **Data set** box to select the data set to be analyzed. Select the data set with the attributes **SCEN RCH5 FLOW** from the **Select data for endpoints** form. This endpoint will look at minimum summer flow, so select **Min** from the **Attribute** list. The form should now appear as below.

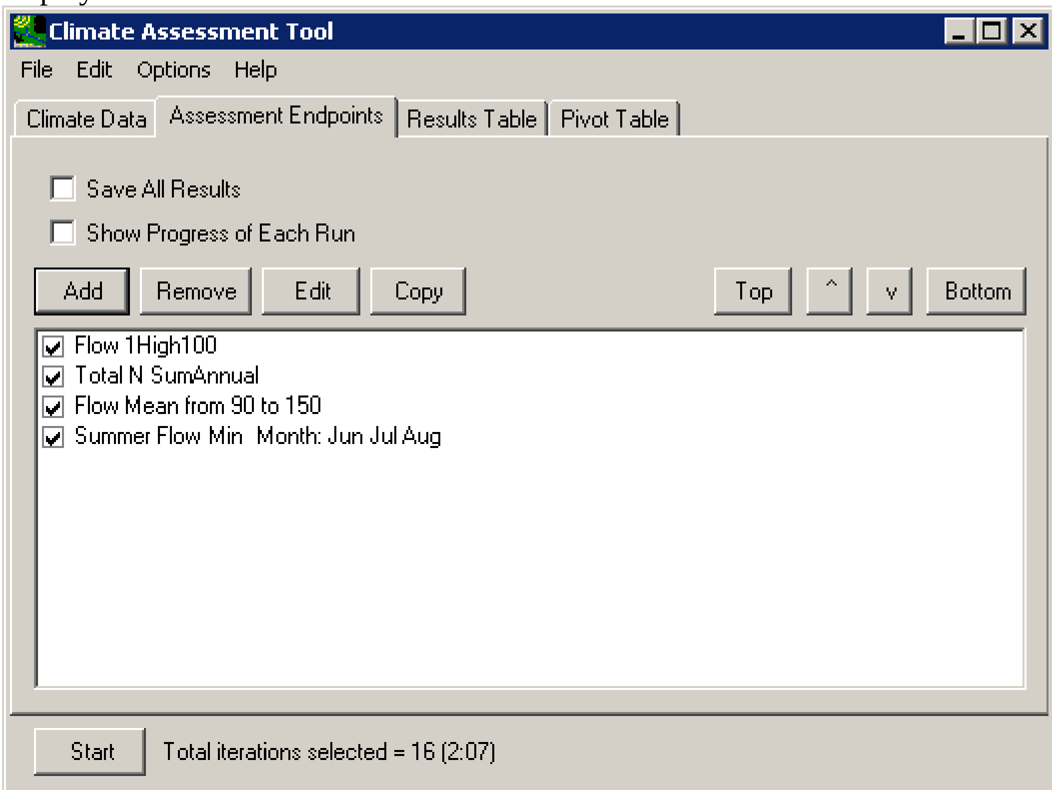


2. The **Seasons** frame near the bottom of the form is used for specifying a time subset to be used when computing the endpoint value. Begin defining this subset by clicking on the **Only include values in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the

item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. For this example, select the **Months** option and the second field will be populated with the months of the year. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items. To report endpoint values during summer months, select **Jun**, **Jul**, and **Aug**.



3. Click the **Ok** to complete defining of this endpoint. The newly created endpoint will be displayed on the **Climate Assessment Tool** form.

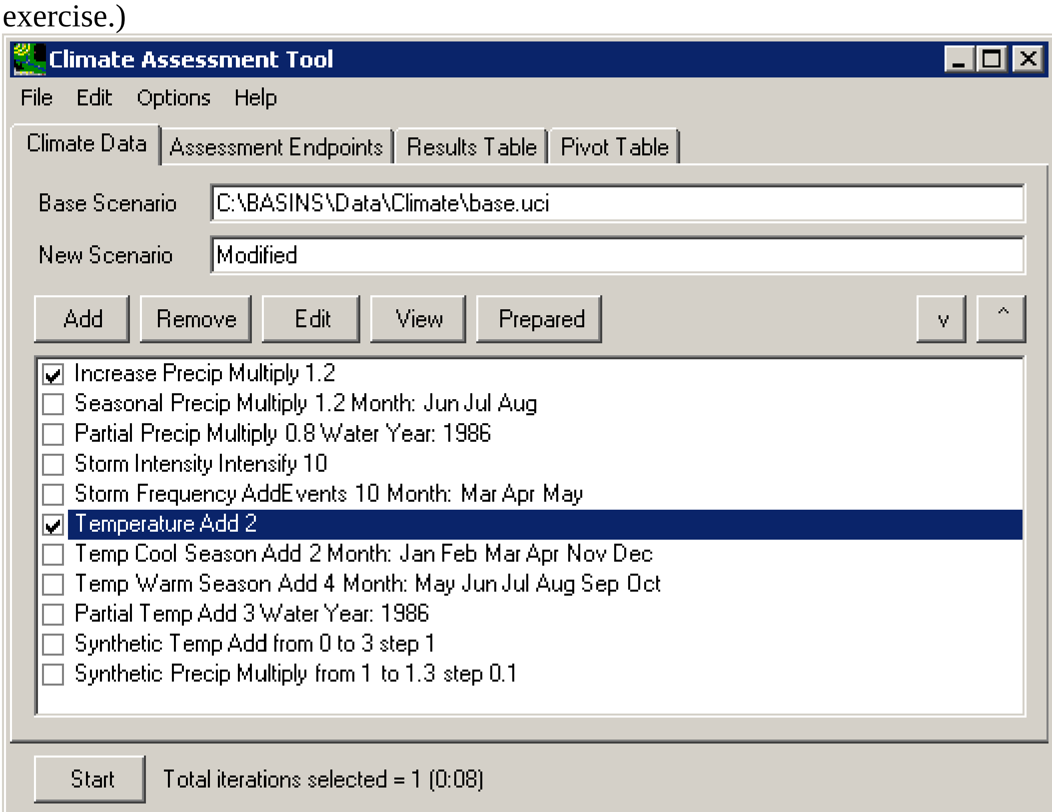


3.3 Running an HSPF Simulation Using BASINS CAT

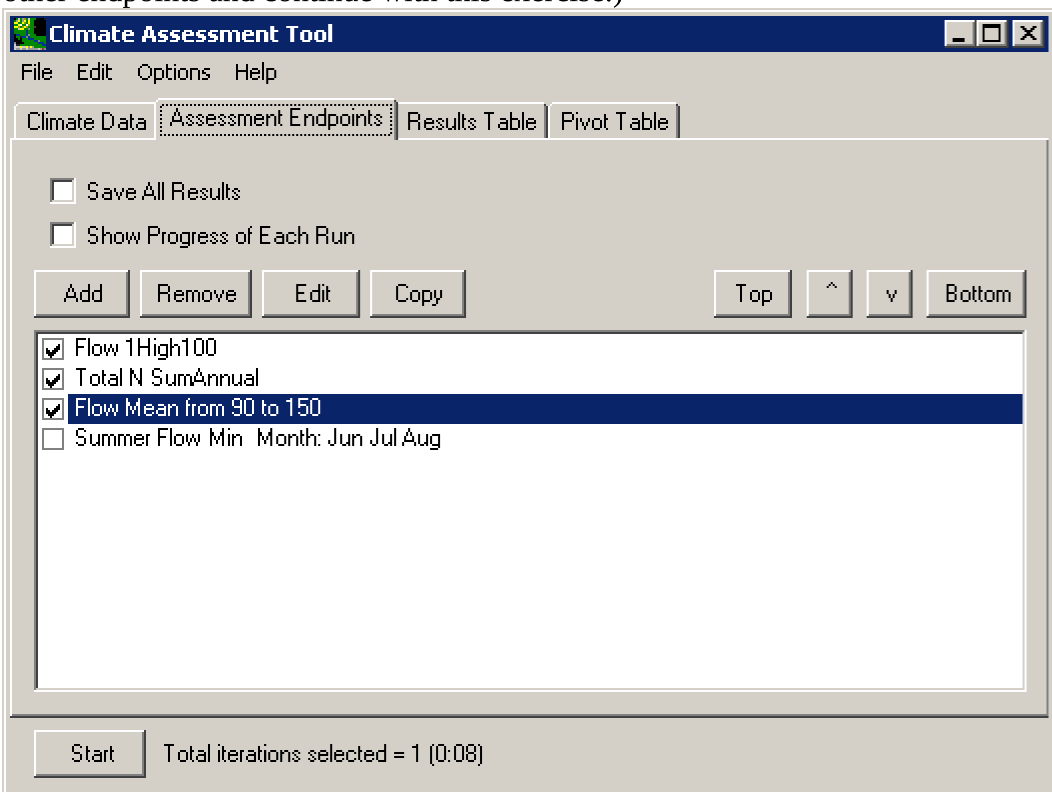
To begin this tutorial, at least one climate scenario and one environmental endpoint must be defined. Climate change scenarios are defined by selecting any number of climate adjustments developed in the tutorials under Section 3.1. Environmental endpoints are defined in the tutorials under Section 3.2.

This tutorial will show how to run a climate assessment using a climate scenario and environmental endpoints. Although this tutorial references climate adjustments and environmental endpoints defined in specific tutorials, it is possible to perform this tutorial using other adjustments and endpoints.

1. The first step in performing an assessment is to define the climate scenario(s) to be run by the model. The tutorial in Section 3.1.3 provides examples of this task. Using that tutorial's first scenario as an example, go to the **Climate Data** tab and select the two climate adjustments shown below to build a climate scenario for this assessment. (Note: If you did not perform the tutorials that developed these climate adjustments, you may select other adjustments to build a different climate scenario and continue with this exercise.)

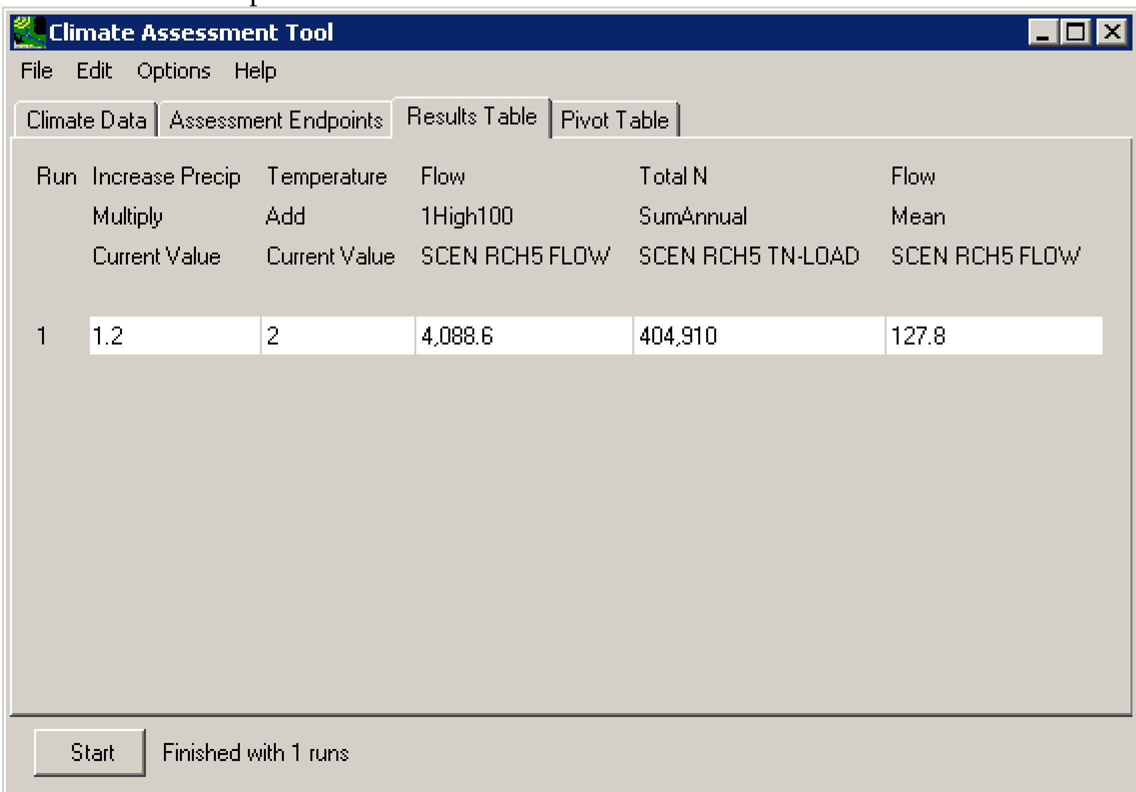


2. The next step in performing an assessment is selecting environmental endpoints of interest. Any number of endpoints may be selected for output from the model run(s). For this example, go to the **Assessment Endpoints** tab and select the endpoints shown below. (Note: If you did not perform the tutorials that developed these endpoints, you may select other endpoints and continue with this exercise.)



3. Before model execution, two additional options on the **Assessment Endpoints** tab may be set: **Save All Results** and **Show Progress of Each Run**. The **Save All Results** check box is used to set whether or not all model output is saved, not just the assessment endpoint values. Checking this box will save a new set of output results in the same manner as the original output. The text from the **New Scenario** field on the **Climate Data** tab will be used as the base file name for the new output files. When saving results from synthetic scenarios, this base name will also have model run number added to it (i.e. “modified-1”, “modified-2”, etc.). The **Show Progress of Each Run** check box is used to set whether or not a status monitor will be displayed while the model is running. If a model run is particularly long, or a series of model runs are being made using synthetic data, checking this box can be useful to see the progress of the model run(s). For this example, leave these two boxes unchecked. Click the **Start** button to make the model

run and see the endpoint results.



3.4 Tools for Summarizing and Visualizing Results

As a component of the BASINS system, BASINS CAT has a variety of output capabilities useful for summarizing and visualizing the results of HSPF simulations. The CAT interface provides standard tabular (results table) and pivot table options. Additional graphics and data listings are also available from within the BASINS system.

The tutorials in this section illustrate the following output capabilities:

- Results Tables - CAT's tabular output of assessment endpoint values
- Pivot Tables - CAT's pivot table output of assessment endpoint values
- Exporting Results - output of assessment endpoint values to files in a format that can be analyzed or visualized using external software
- Additional BASINS Tools - analysis and display features available in BASINS

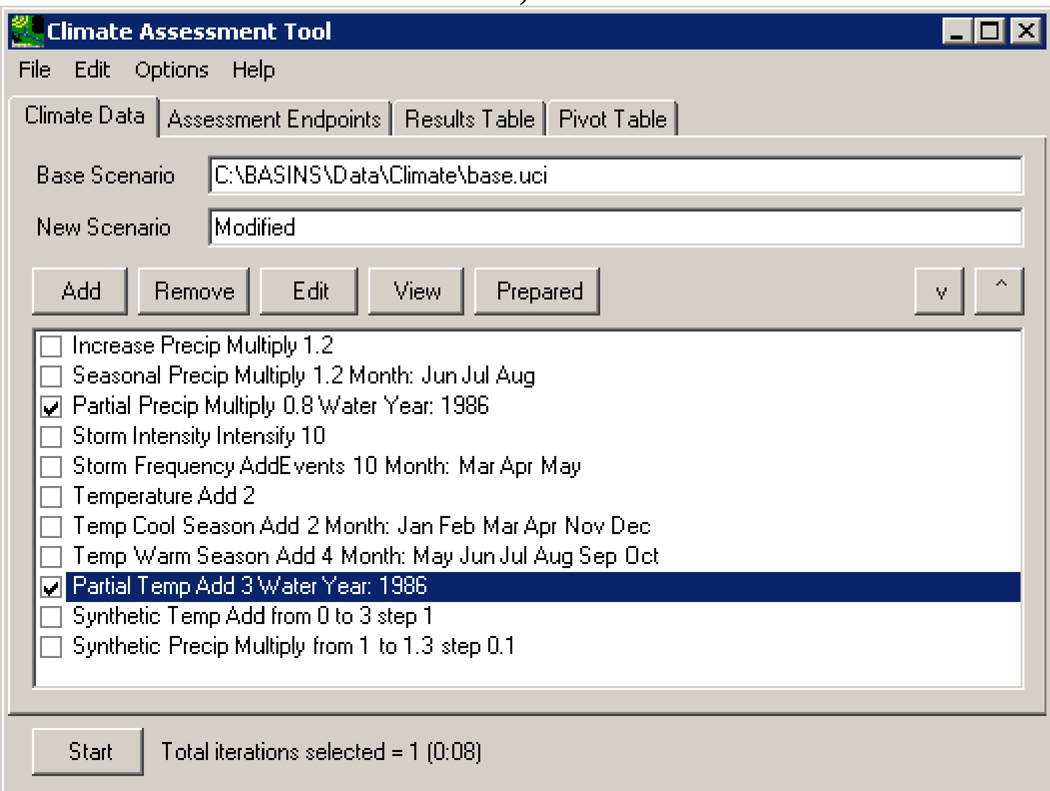
3.4.1 Results Tables

To begin this tutorial, at least one climate scenario and one environmental endpoint must be defined. Climate change scenarios are defined by selecting any number of climate adjustments developed in the tutorials under Section 3.1. Environmental endpoints are defined in the tutorials under Section 3.2.

This tutorial will demonstrate CAT's standard tabular output capabilities by running an assessment. Although this tutorial references climate adjustments and environmental endpoints developed in specific tutorials, it is possible perform this tutorial using other adjustments and endpoints.

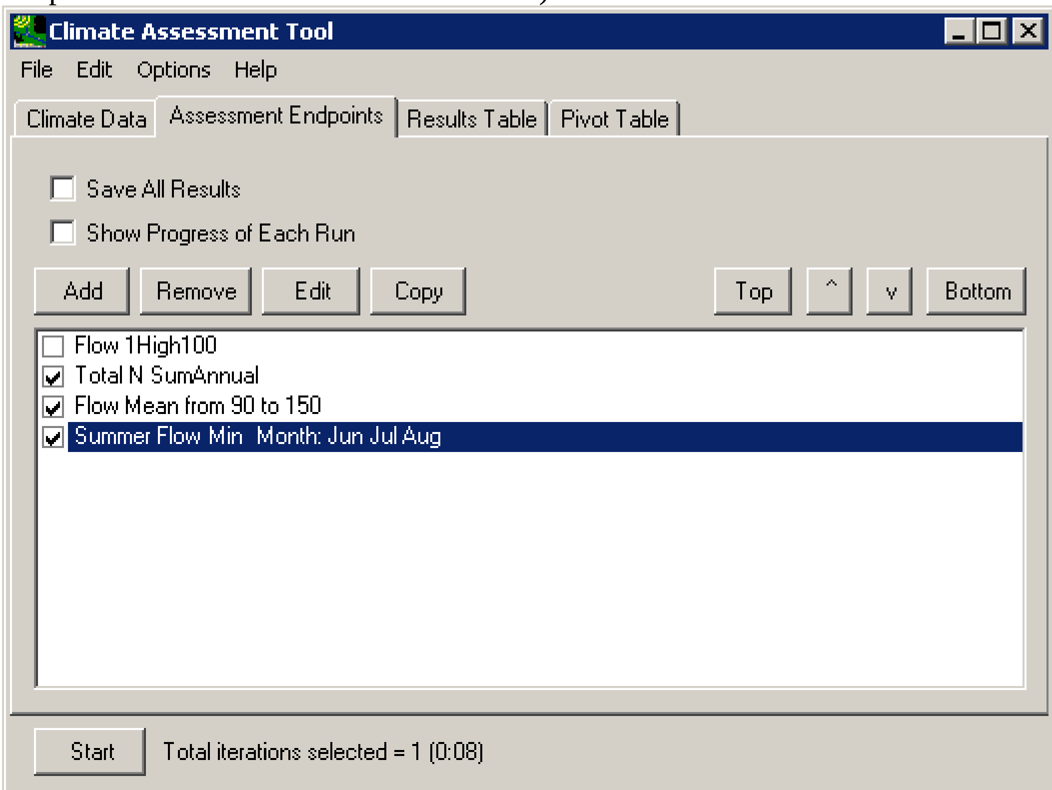
1. Begin this example by defining a climate scenario. Following the second example from the tutorial in Section 3.1.3, go to the **Climate Data** tab and select the climate adjustments shown below. (Note: If you did not perform the tutorials that developed these climate adjustments, you may select other adjustments to build a different climate

scenario and continue with this exercise.)



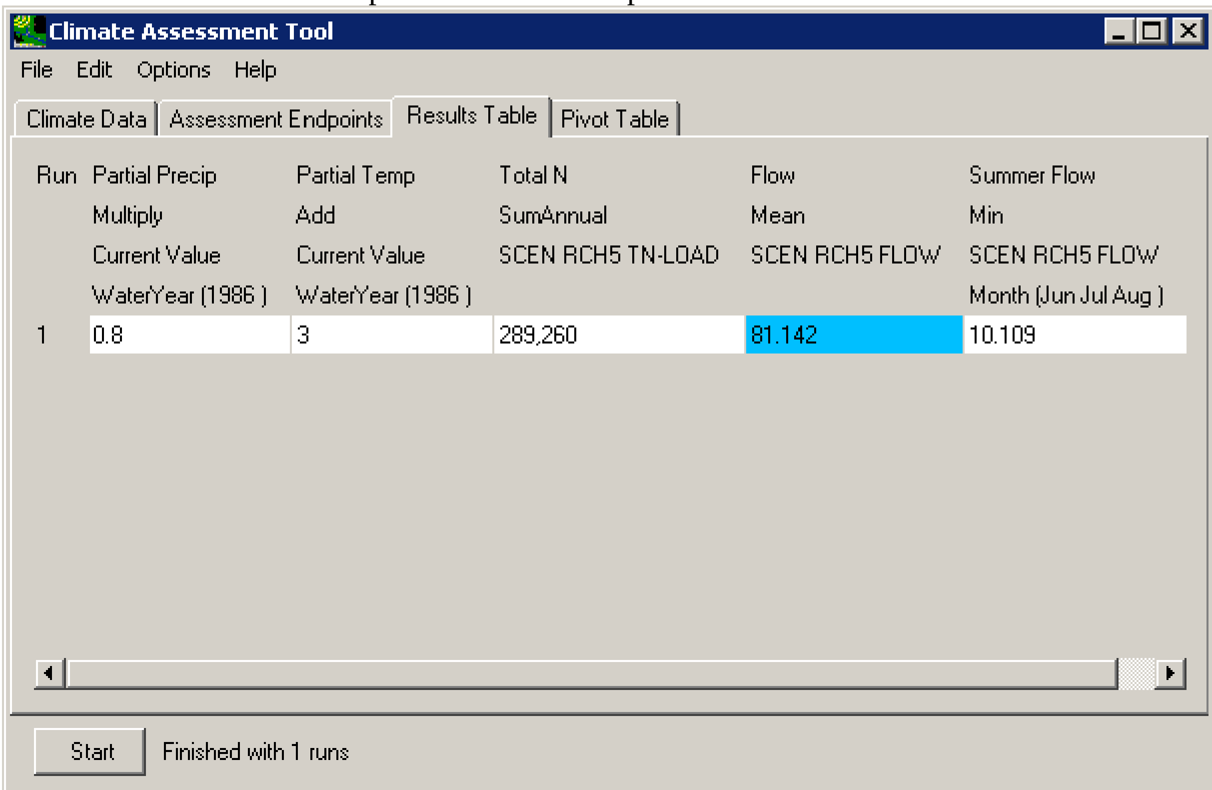
2. Now select the environmental endpoints of interest for this assessment. For this example, go to the **Assessment Endpoints** tab and select the endpoints shown below. (Note: If you did not perform the tutorials that developed these endpoints, you may select other

endpoints and continue with this exercise.)



3. To execute the model run for this assessment, click the **Start** button at the bottom of the form. When the model has completed, CAT will report the resulting endpoint values on the **Results Table** tab. The CAT form may be resized to show all resulting values at the same time. Note that for this assessment, the average flow value falls below the

minimum value of concern specified for that endpoint.



4. Output tables in CAT may also be saved to an external file for use outside of the program. Choose the **Save Results** item from the **File** menu and a dialogue form will prompt for the file name in which the results are to be saved. Results are saved in a tab-delimited format, suitable for import into Excel and other analysis programs.

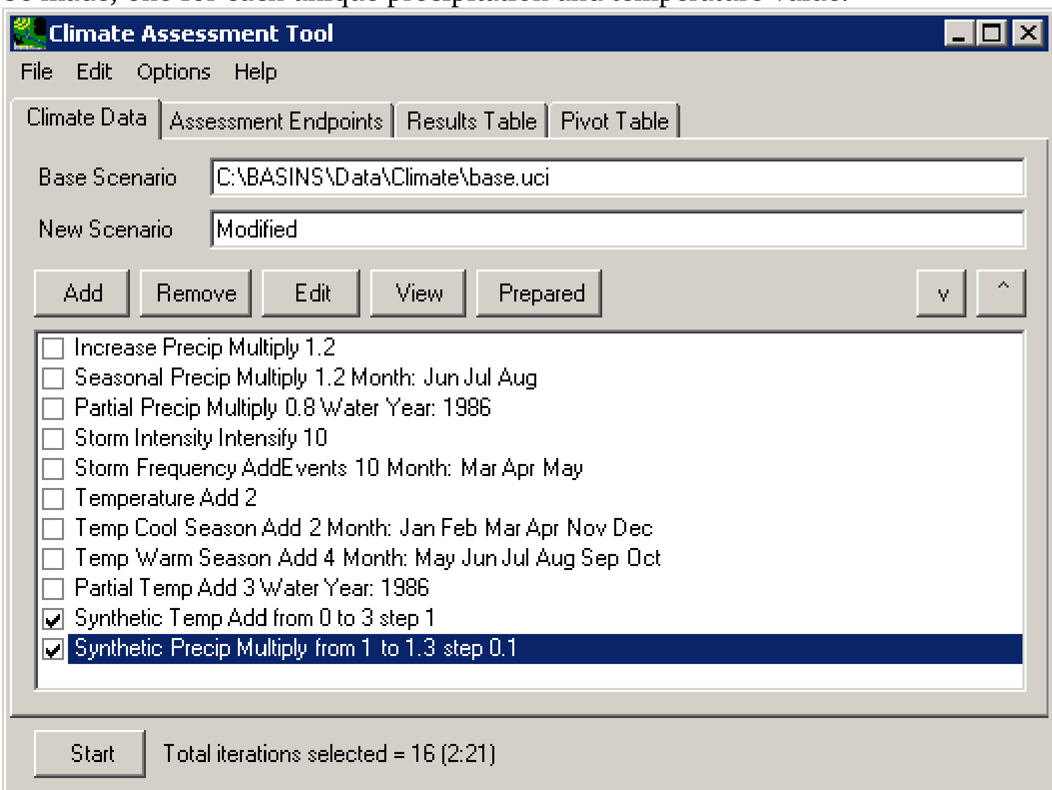
3.4.2 Pivot Tables

A pivot table is a data visualization and mining tool that allows users to reorganize selected columns and rows of data within a database. The term pivot refers to turning the data to view it from different perspectives. Pivot tables are especially useful for summarizing large amounts of data in a compact format, looking for patterns and relationships within a dataset, and organizing data into a format suitable for plotting data as a chart.

To perform this tutorial, the tutorial in Section 3.1.4 must have been run to create synthetic climate change scenarios for precipitation and temperature. Additionally at least one environmental endpoint must be defined. Environmental endpoints are defined in the tutorials under Section 3.2.

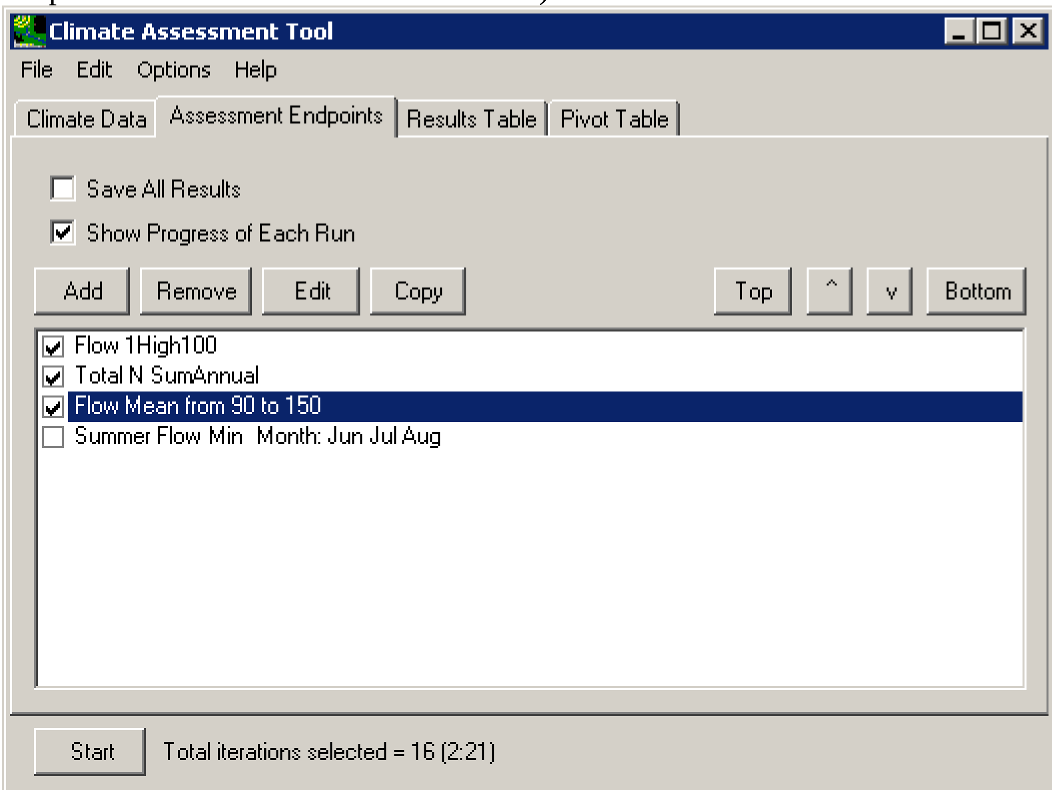
This tutorial will demonstrate CAT's pivot table output capabilities by running an assessment. The pivot table feature provides flexibility in displaying multiple sets of results produced when running synthetic climate change scenarios.

1. Begin this example by defining a climate scenario. On the **Climate Data** tab select the two synthetic climate change scenarios developed in Section 3.1.4, as shown below. Note that since each synthetic scenario has four iterations, a total of 16 model runs will be made, one for each unique precipitation and temperature value.



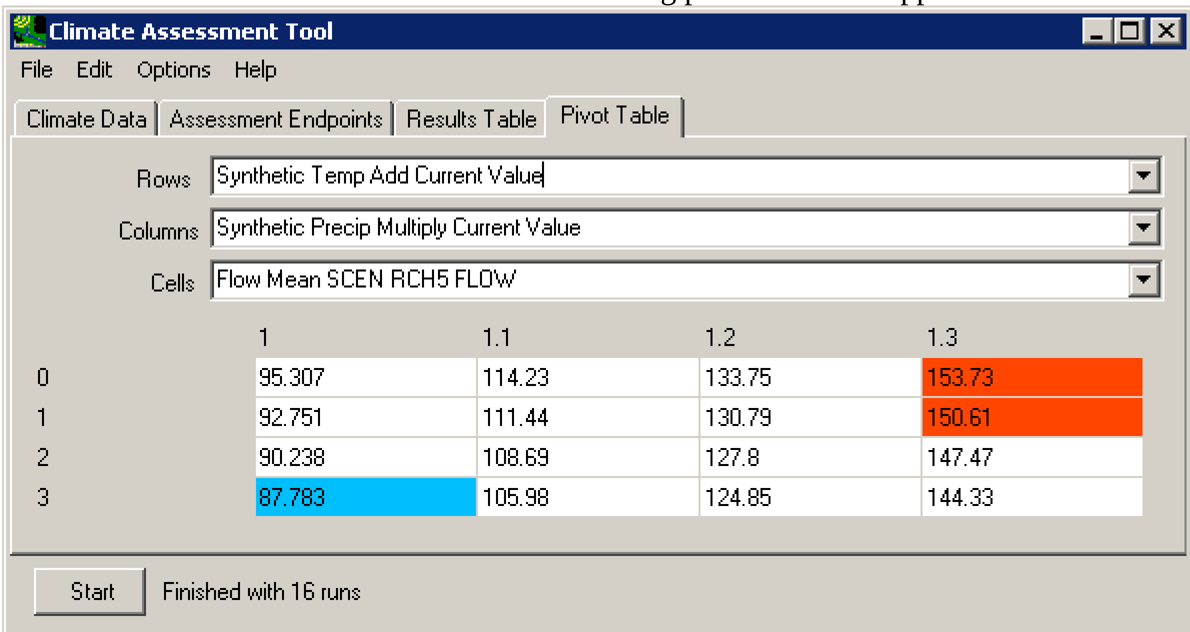
2. Now select the environmental endpoints of interest for this assessment. For this example, go to the **Assessment Endpoints** tab and select the endpoints shown below. (Note: If you did not perform the tutorials that developed these endpoints, you may select other

endpoints and continue with this exercise.)



3. Since this assessment will involved 16 model runs, it is advisable to “check on” the **Show Progress of Each Run** option. To execute the model run for this assessment, click the **Start** button at the bottom of the form. When the model has completed, CAT will report the resulting endpoint values on the **Results Table** tab. Now click on the **Pivot Table** tab to explore additional CAT output features. The first two fields of this form are used to specify what element to vary in the **Rows** and **Columns** of the pivot table. For this exercise, select **Synthetic Temp Add Current Value** and **Synthetic Precip Add Current Value** for the **Rows** and **Columns** field values. The **Cells** field is used to specify what element will be displayed in the pivot table’s cells. Select **Flow Mean**

SCEN RCH5 FLOW for this field and the resulting pivot table will appear as follows.



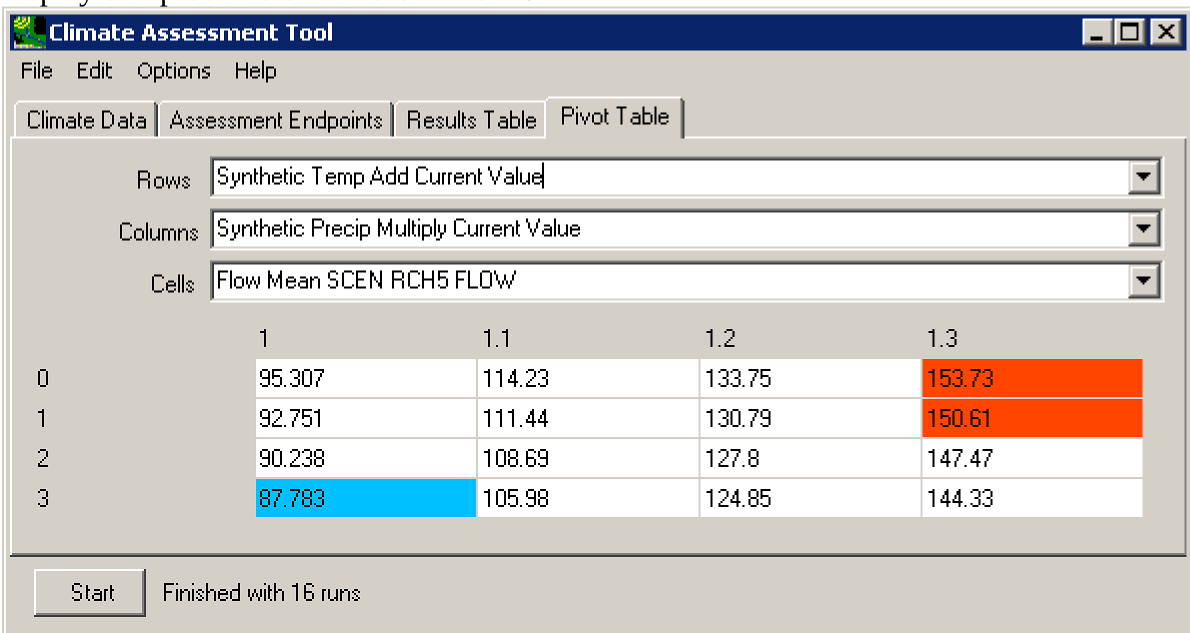
4. Note that some of the flow values fall below or above the minimum and maximum values of concern that were specified when defining this endpoint. As desired, familiarize yourself with the pivot table's capabilities by changing the selections in the 3 fields above the table.

3.4.3 Exporting Results for Use With External Software

To perform this tutorial, it is necessary to complete the previous Pivot Tables tutorial in Section 3.4.2. This tutorial continues the assessment performed in the previous section where synthetic temperature and precipitation scenarios were run and a pivot table of the results was created.

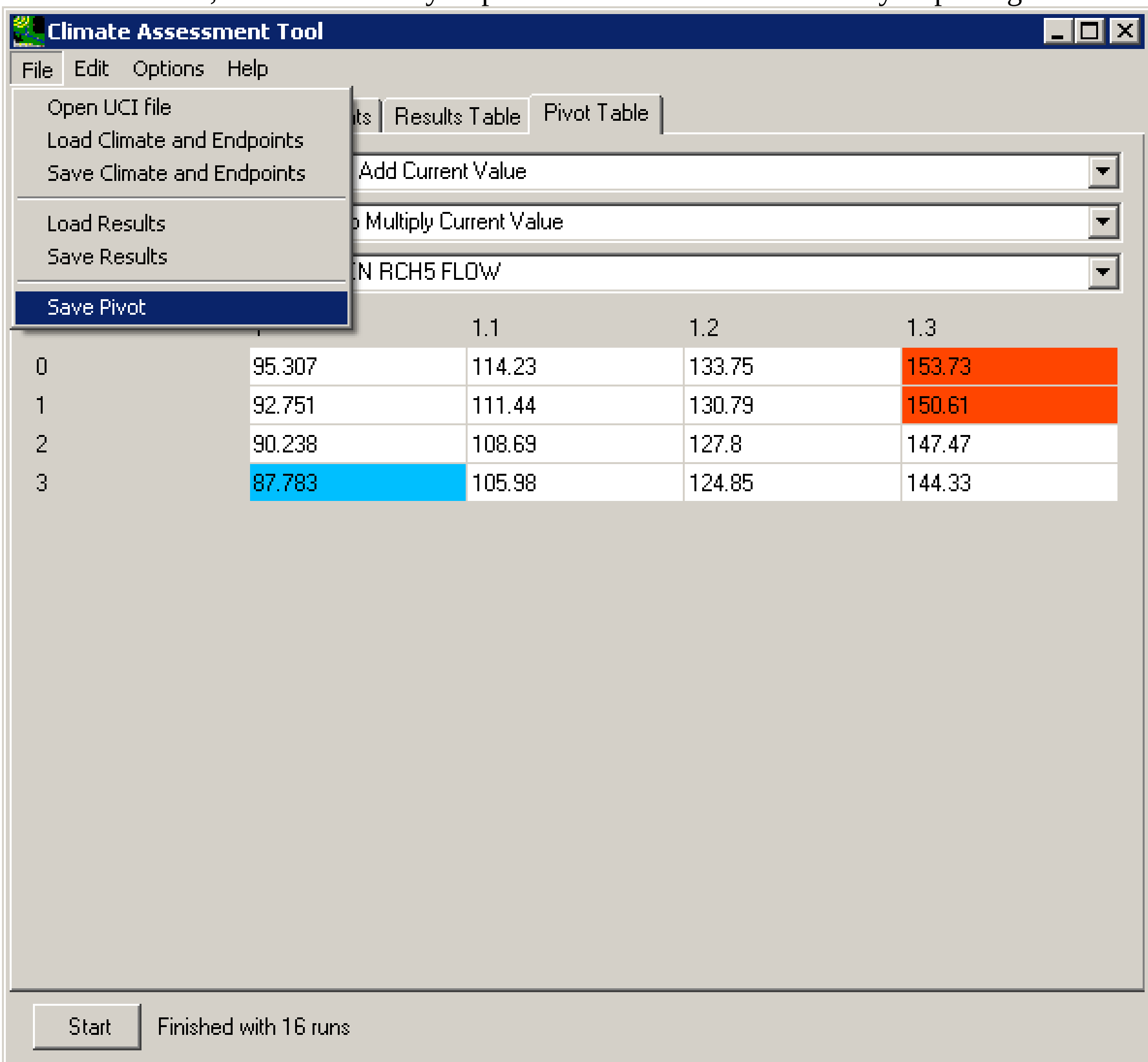
This tutorial will demonstrate how results from CAT can be exported for analysis or data visualization using external software.

1. This tutorial begins with the final step of the previous tutorial, which should be the display of a pivot table on the CAT form.

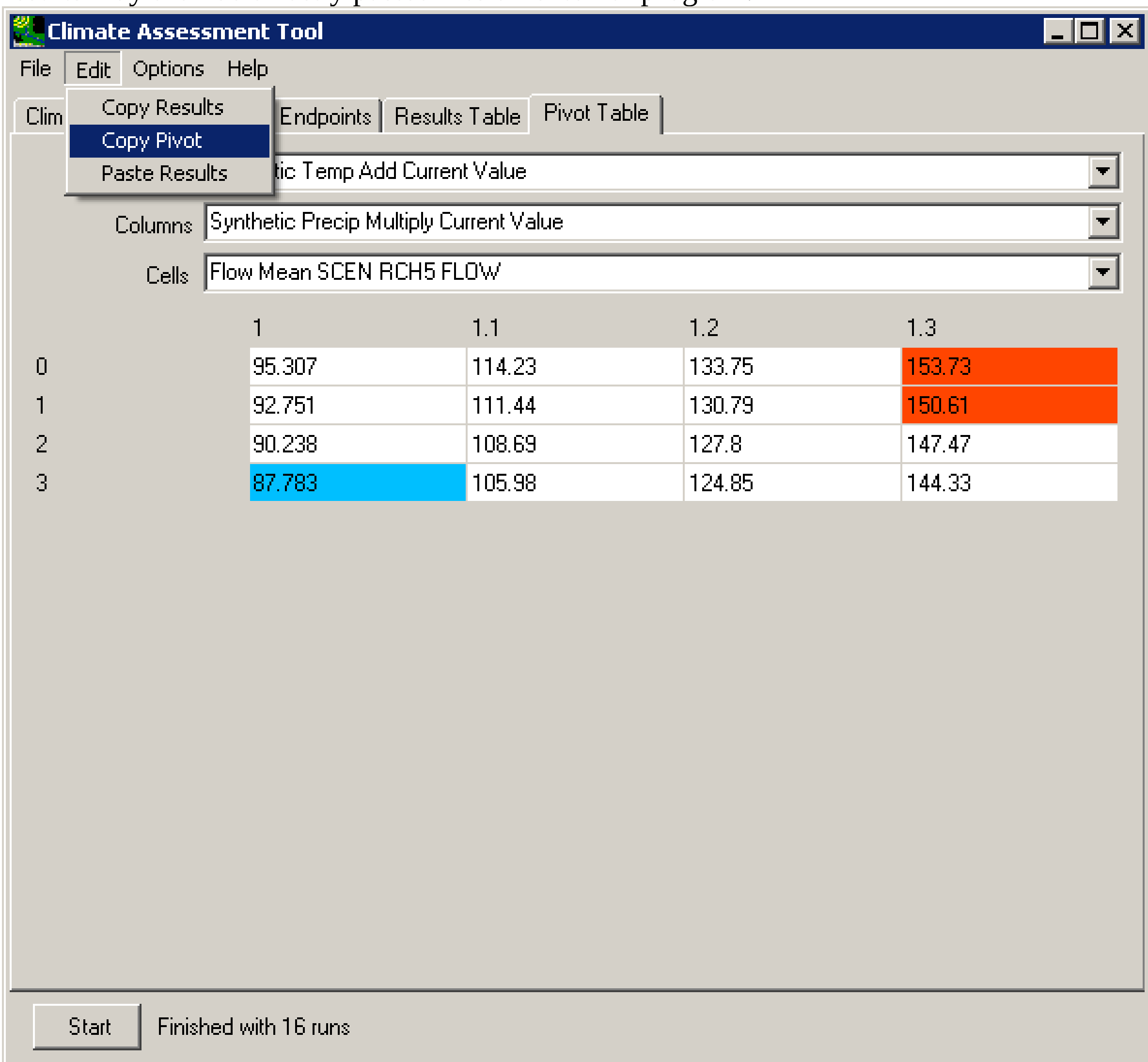


2. Output results from both the **Results Table** and the **Pivot Tables** may be saved to an external file. Use the **File** menu to access options for saving either table. A file dialogue will then prompt for the name of the output file. The results will be saved in a tab-

delimited format, which are readily imported into Excel and other analysis packages.



3. In the same manner, results from both tables may also be copied to the clipboard. The results may then be directly pasted into an external program.



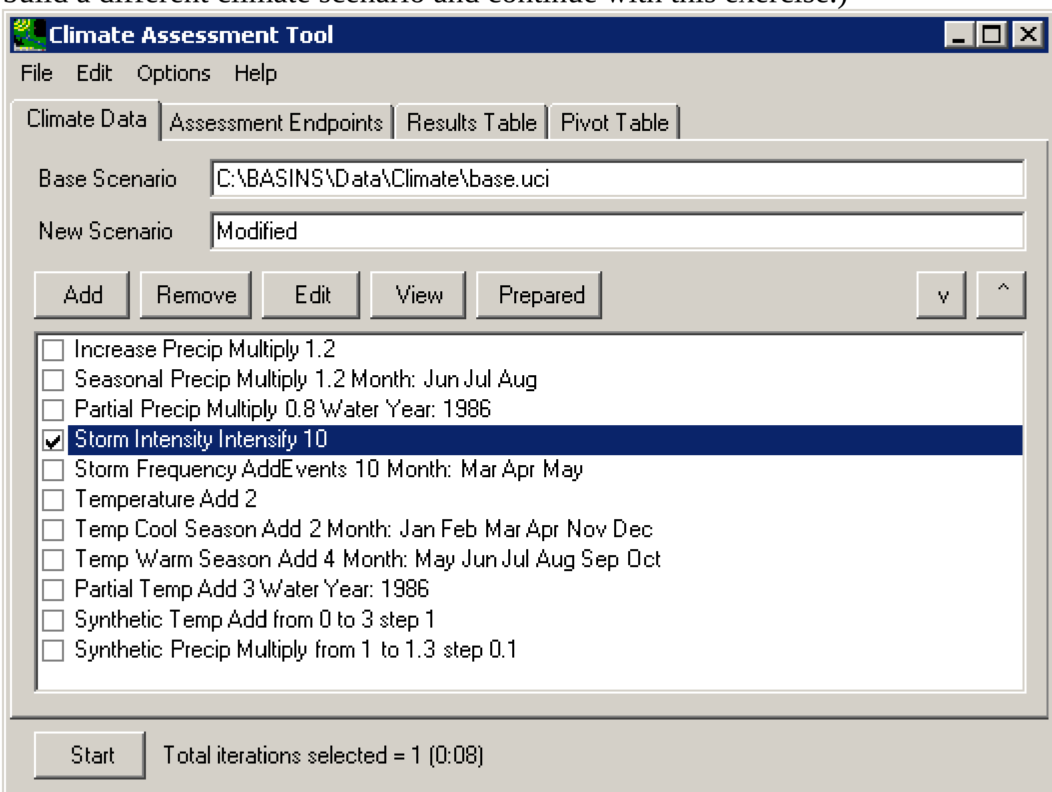
Using either of the above exporting capabilities, results from HSPF simulations conducted using BASINS CAT can be exported for analysis and/or visualization using any external software.

3.4.4 Additional BASINS Tools

To begin this tutorial, at least one climate scenario and one environmental endpoint must be defined. Climate change scenarios are defined by selecting any number of climate adjustments developed in the tutorials under Section 3.1. Environmental endpoints are defined in the tutorials under Section 3.2.

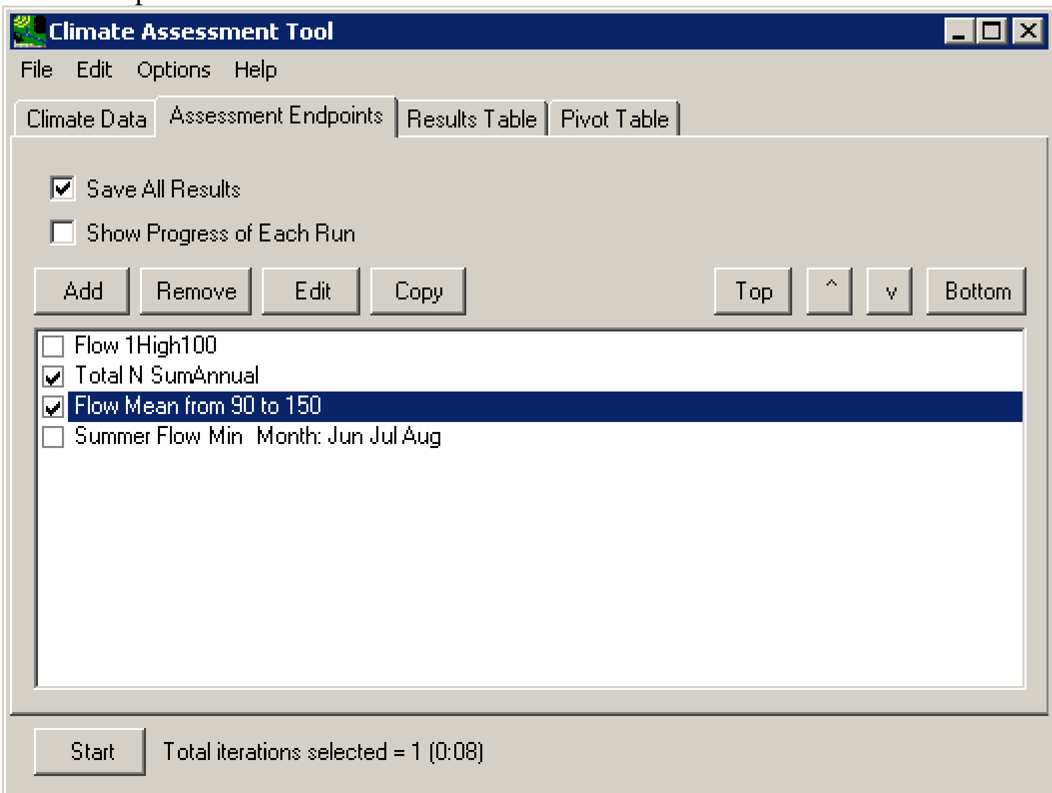
This tutorial will demonstrate how to access additional output and analysis capabilities in BASINS that can aid in an assessment. Although this tutorial references climate adjustments and environmental endpoints developed in specific tutorials, it is possible perform this tutorial using other adjustments and endpoints.

1. Begin this example by defining a climate scenario. For this example a simple scenario of intensifying precipitation will be used as shown below. (Note: If you did not perform the tutorial that developed this climate adjustment, you may select another adjustment to build a different climate scenario and continue with this exercise.)



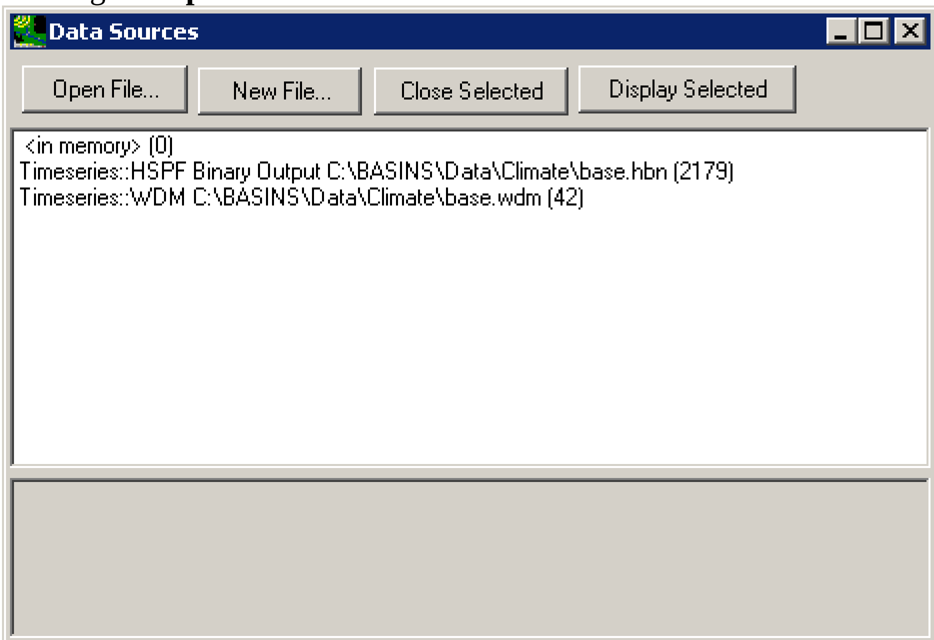
2. Now select the environmental endpoints of interest for this assessment. This example will focus on total nitrogen loads, so go to the **Assessment Endpoints** tab and select the endpoints shown below. (Note: If you did not perform the tutorials that developed these endpoints, you may select other endpoints and continue with this exercise.) This exercise will demonstrate further analysis capabilities within BASINS, so be sure the “Save All

Results” option is on.

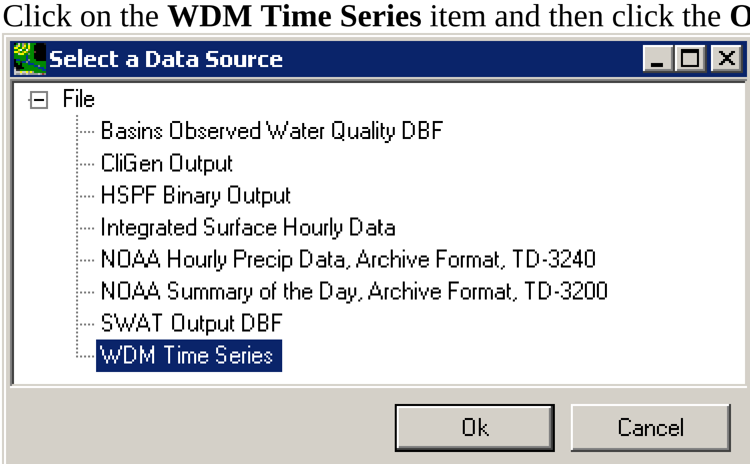


3. To execute the model run for this assessment, click the **Start** button at the bottom of the form. When the model has completed, CAT will report the resulting endpoint values on the **Results Table** tab. To begin using BASINS analysis tools, return to the main BASINS form and select the **Manage Data** option from the **File** menu. The **Data Sources** form shows the data sources that are currently open, these being the WDM and binary output (hbn) file from the Base run. From here the results from the modified climate scenario may be loaded into the current BASINS project. Begin this process by

clicking the **Open File** button.

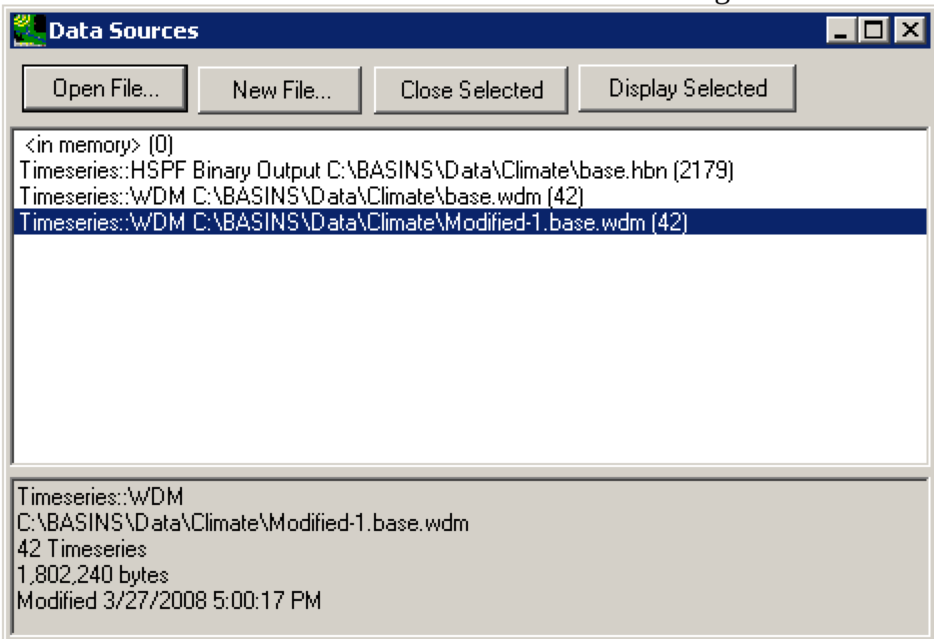


4. The **Select a Data Source** form displays the various data formats that BASINS can read. Click on the **WDM Time Series** item and then click the **Ok** button.



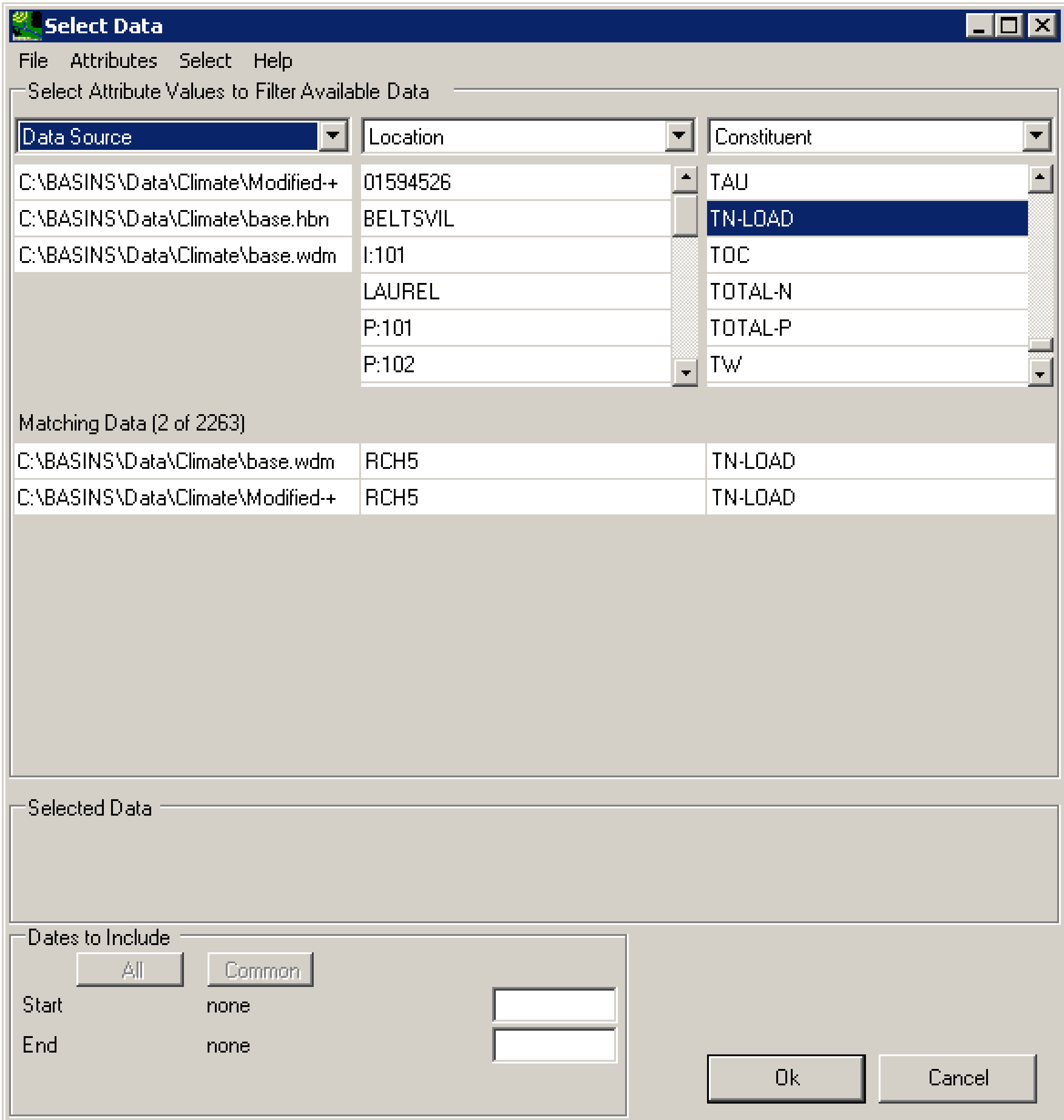
5. On the ensuing dialogue form, select the WDM file starting with ‘modified’, which contains updated input and output from the climate scenario run during this exercise. The

Data Sources form should now list this WDM file along with the 'Base' files.



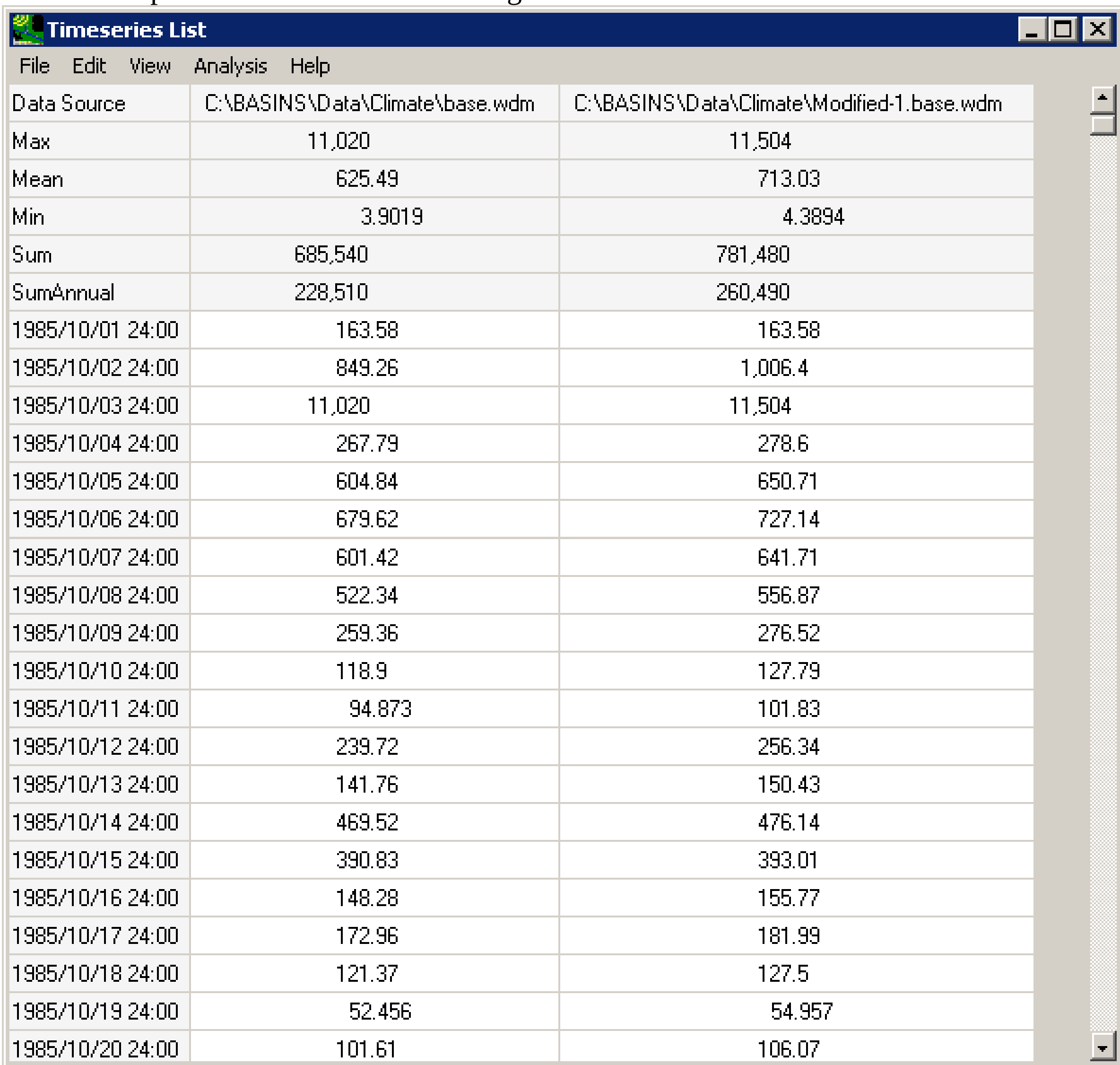
6. The **Data Sources** window may now be closed. The **Analysis** menu contains a variety of features to aid in assessment. To view the daily Nitrogen loads, select the **List** option from this menu and you will be prompted for the data sets to be listed. In the third column, labeled **Constituent**, scroll down and select the **TN-LOAD** item. Two data sets with the same **Scenario**, **Location**, and **Constituent** are available. To distinguish between the two it is necessary to change the attribute listed in one of the three columns. Go to the first column, labeled **Scenario**, and click the pull-down list at the top of the column. Scroll up the list and select the **Data Source** attribute, which will show the file

name of each data set.



7. Clicking the **Ok** will automatically select the two **Matching** data sets and generate the listing of the data sets' values. A variety of attributes are available for display at the top of the listing. These are accessed through the **File:Select Attributes** menu option.

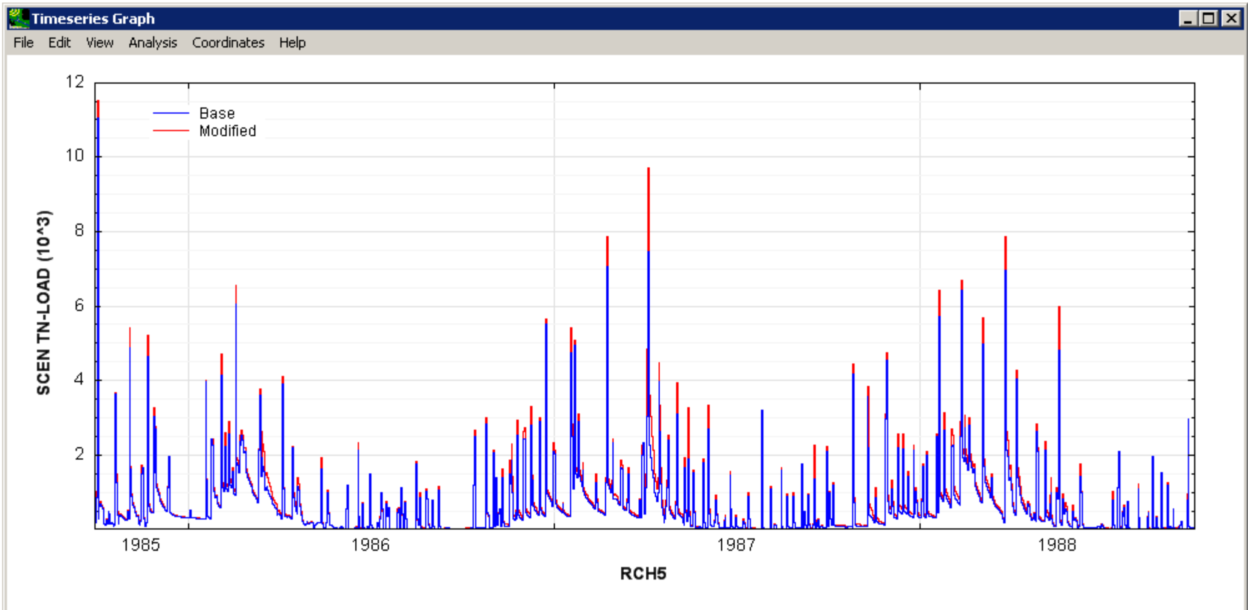
Select this option and customize the listing as desired.



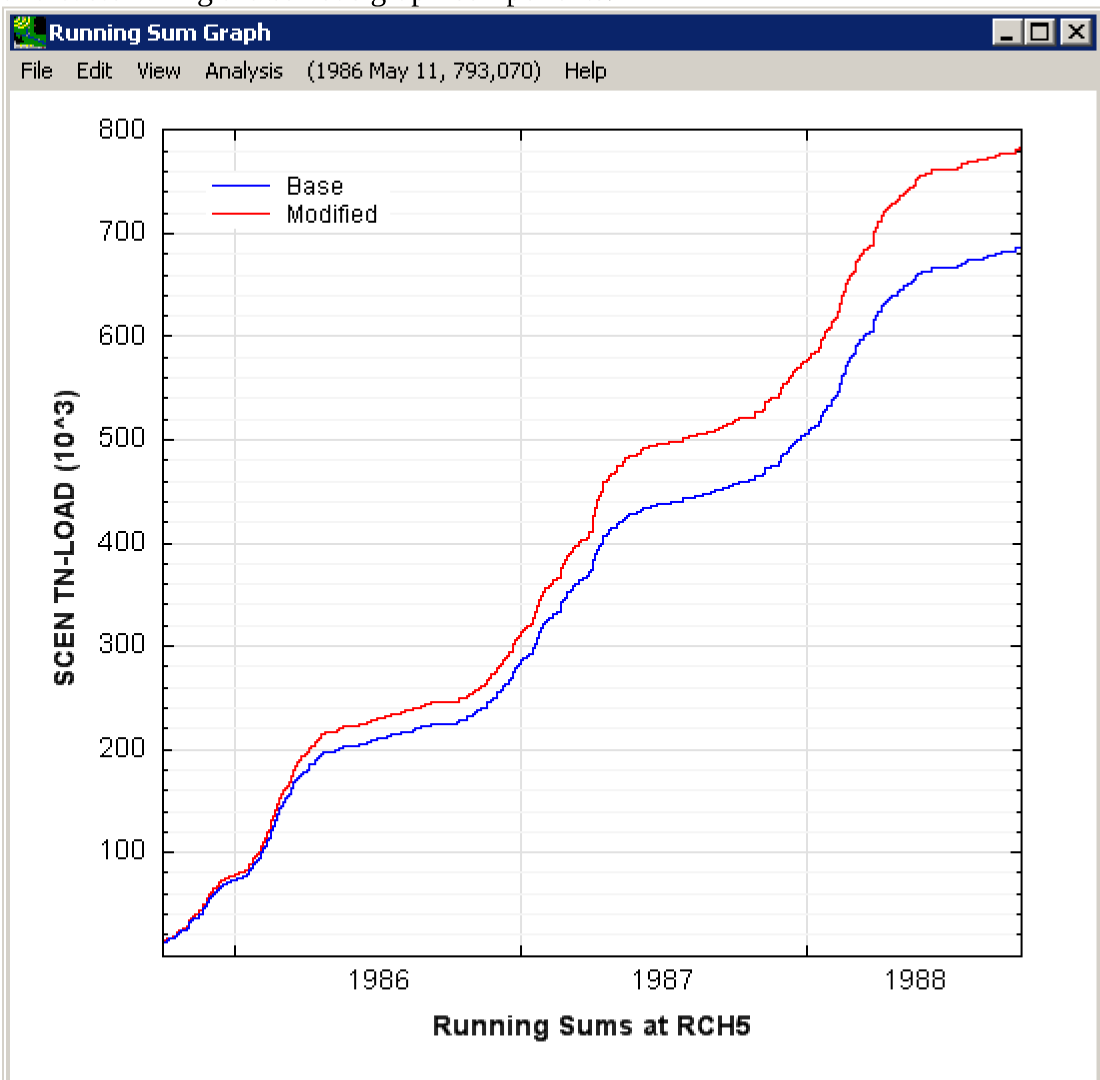
Data Source	C:\BASINS\Data\Climate\base.wdm	C:\BASINS\Data\Climate\Modified-1.base.wdm
Max	11,020	11,504
Mean	625.49	713.03
Min	3.9019	4.3894
Sum	685,540	781,480
SumAnnual	228,510	260,490
1985/10/01 24:00	163.58	163.58
1985/10/02 24:00	849.26	1,006.4
1985/10/03 24:00	11,020	11,504
1985/10/04 24:00	267.79	278.6
1985/10/05 24:00	604.84	650.71
1985/10/06 24:00	679.62	727.14
1985/10/07 24:00	601.42	641.71
1985/10/08 24:00	522.34	556.87
1985/10/09 24:00	259.36	276.52
1985/10/10 24:00	118.9	127.79
1985/10/11 24:00	94.873	101.83
1985/10/12 24:00	239.72	256.34
1985/10/13 24:00	141.76	150.43
1985/10/14 24:00	469.52	476.14
1985/10/15 24:00	390.83	393.01
1985/10/16 24:00	148.28	155.77
1985/10/17 24:00	172.96	181.99
1985/10/18 24:00	121.37	127.5
1985/10/19 24:00	52.456	54.957
1985/10/20 24:00	101.61	106.07

8. The **Analysis** menu on the **Time series List** form contains many of the same analysis functions as the main BASINS form. Select the **Graph** option from the Analysis menu and the **Choose Graphs to Create** form is displayed. To see two examples of different graphs, select the **Time series** and **Running Sum** graphs and then click the **Generate**

button.


Timeseries Graph
File Edit View Analysis Coordinates Help
Base
Modified
SCEN TN-LOAD (10^3)
12
10
8
6
4
2
1985
1986
1987
1988
RCH5

9. BASINS graphs may be manipulated in a variety of ways including resizing, zooming, and customizing the various graph components.

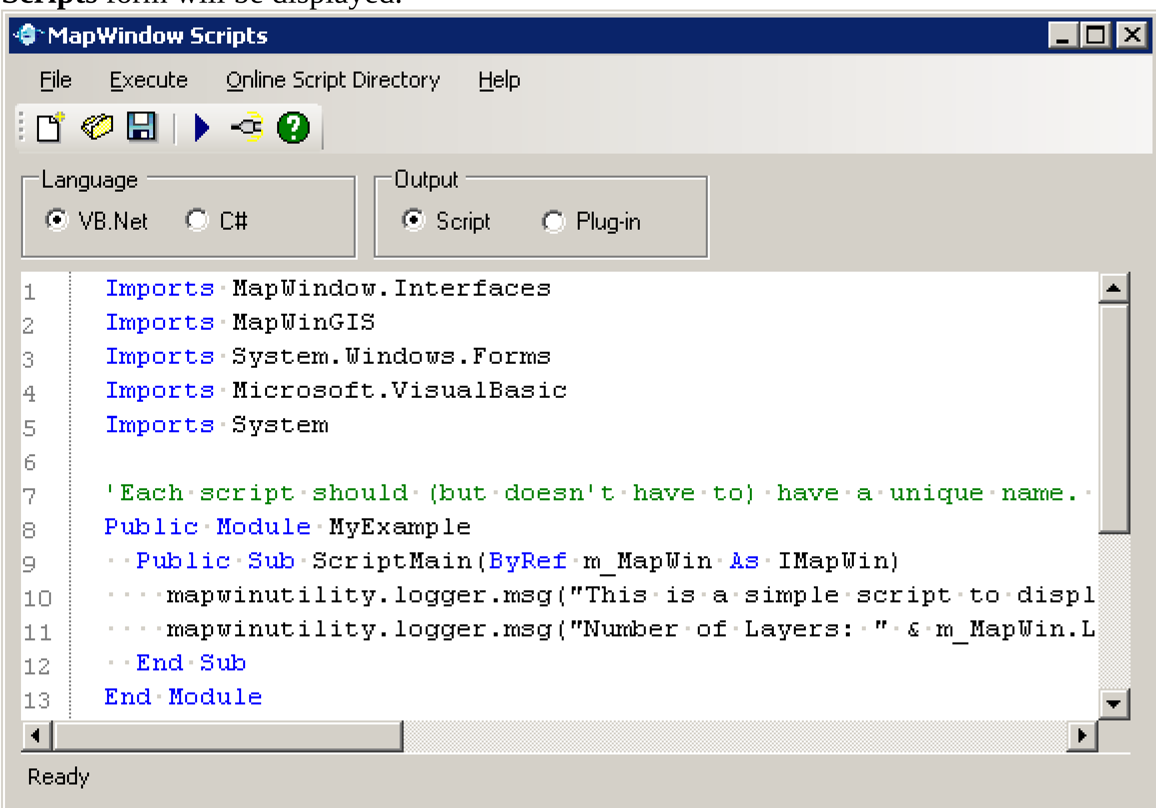


10. Along with listing and graphing, BASINS contains many other time series analysis features including duration-frequency computations, seasonal statistic computation, generation of additional time series from existing time series, and creation of time series of distinct events that are above or below a threshold.

3.5 Using Scripts to Automate CAT Applications

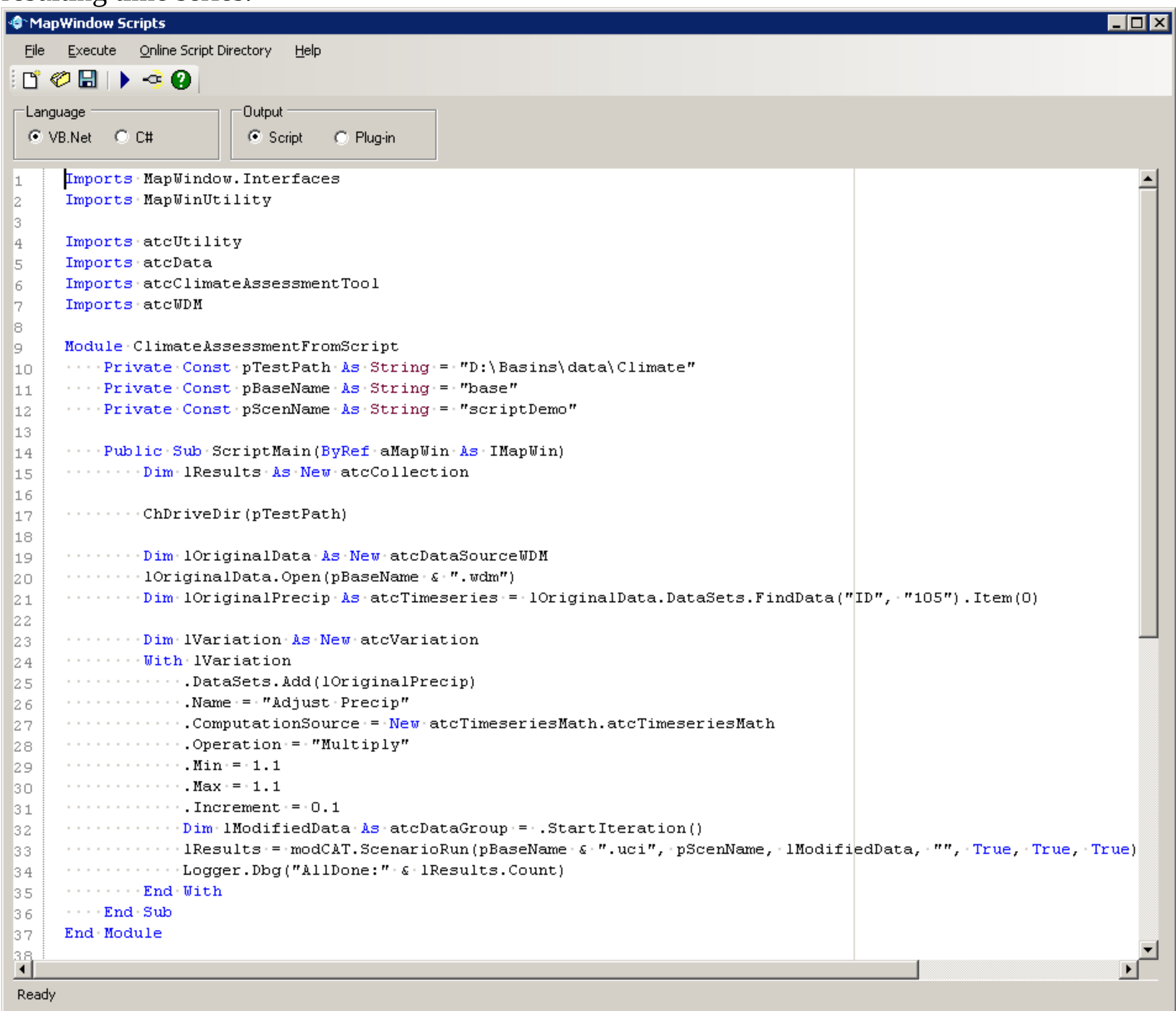
This tutorial is run from the main BASINS form and requires no actual CAT interaction. The purpose of this tutorial is to demonstrate how to run scripts from BASINS to perform CAT functions. Scripts provide a way to automate repetitive tasks in CAT and also leave a track record of how procedures were accomplished.

Begin this tutorial by leaving the CAT form and returning to the main BASINS form. Scripts written in .Net programming languages such as VB.Net or C# may be accessed and run from the BASINS interface. Select the **Scripts...** option from the **Plug-ins** menu and the **MapWindow Scripts** form will be displayed.



This form provides an interface to open or save existing scripts or to start a new script using the **File** menu or the icons below the menu bar. The **Execute** option allows for a script to be run or for a script to be compiled as a plug-in for use in MapWindow/BASINS. Access to an online repository of scripts is also provided through the **Online Script Directory**.

The code below shows a simple script that performs basic CAT functions. After a number of declarations ("Const" and "Dim" statements), the WDM file is opened (variable "lOriginalData") and the data set to be modified is set (variable "lOriginalPrecip"). The climate variations for this assessment are then specified (variable "lVariation"), including the "Name", the "Operation" type, the “Min” and “Max” value, and the “Increment”. In this case, there will only be one variation, an increase of 10% (i.e. Multiply by 1.1) to the historical precipitation record. The assessment is then run with a call to “modCAT.ScenarioRun” and the model output time series are stored in the variable “lResults”. Lastly, the script simply reports the count of output time series. The script could readily be expanded to extract more detailed information out of the resulting time series.



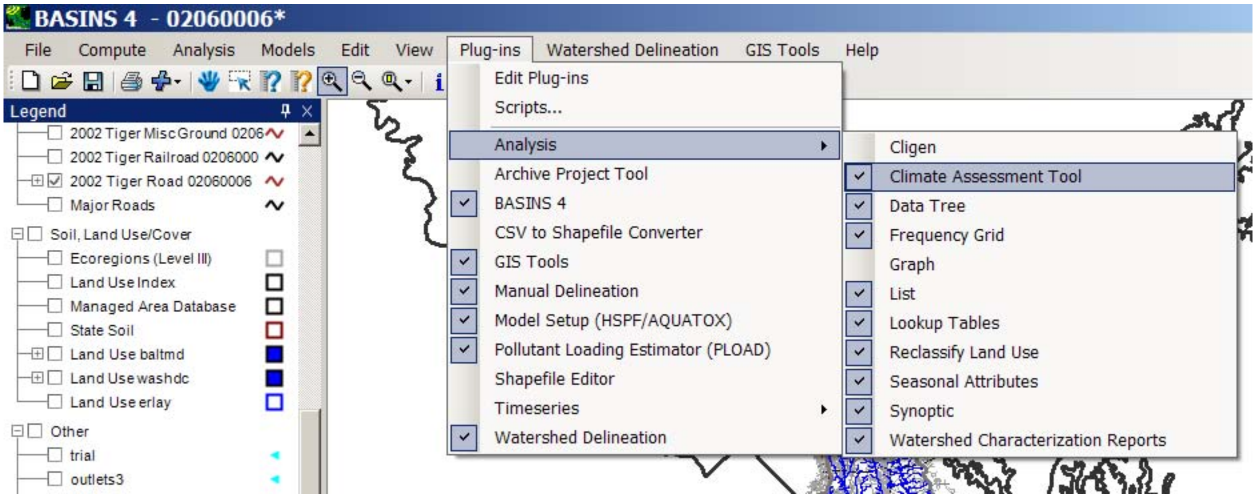
4.0 CAT User’s Manual

The BASINS **Climate Assessment Tool** (**CAT**) provides a flexible set of capabilities for representing and exploring climate change and its relationship to watershed science. Tools have been integrated into the BASINS system allowing users to create climate change scenarios by modifying historical weather data, and to use these data as the meteorological inputs to the Hydrological Simulation Program - FORTRAN (HSPF) watershed model. A capability is also provided to calculate specific hydrologic and water quality endpoints important to watershed management based on HSPF model output (e.g. the 100-year flood or 7Q10 low flow event). Finally, the CAT can be used to assess the outcomes of a single climate change scenario, or to automate multiple HSPF runs to determine the sensitivity or general pattern of watershed response to different types and amounts of climate change.

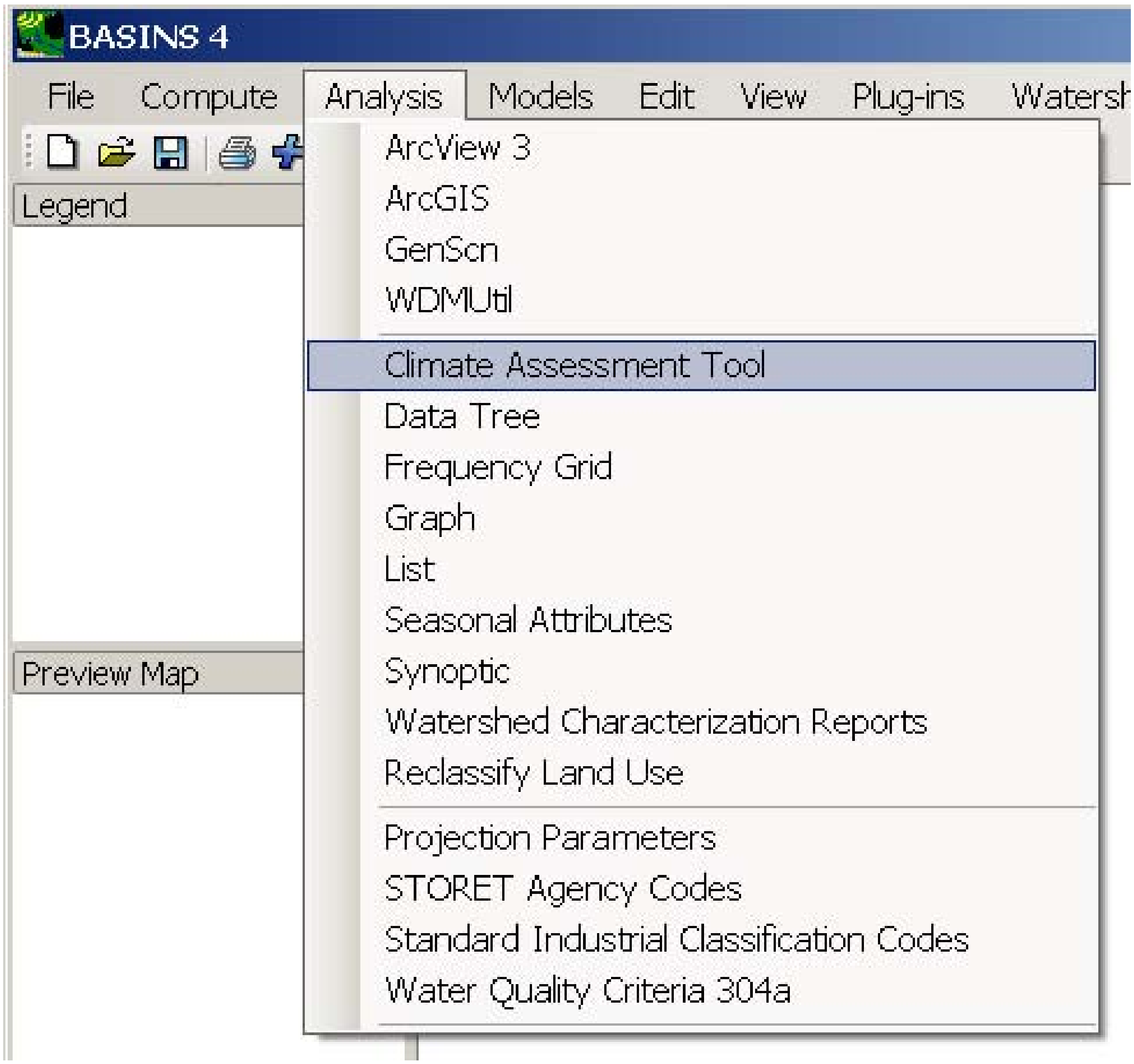
Users can modify historical climate data using standard arithmetic operators applied monthly, seasonally or over any other increment of time. Increases or decreases in a climate variable (precipitation, air temperature) can be applied uniformly, or they can be selectively imposed on only those historical events that exceed (or fall below) a specified magnitude. This capability allows changes to be imposed only on events within user-defined size classes, and can be used to represent the projected effects of ‘intensification’ of the hydrologic cycle, whereby larger precipitation events intensify, instead of events becoming more frequent. In addition, users are able to create time series that contain more frequent precipitation events. These capabilities provide users with an ability to represent and assess the impacts of a wide range of potential future climatic conditions and events.

BASINS CAT does not provide climate change scenario data. Rather, the tool provides a capability for quickly creating and running climate change scenarios within the BASINS system. Diverse sources of information such as records of historical and paleo-extreme events, observed trends, and projections based on global or regional scale climate models can be used to guide scenario development. Data requirements will vary depending on assessment goals. BASINS CAT provides capabilities to support a range of assessment goals, e.g. simple screening analysis, systematic sensitivity analysis, or implementing more detailed scenarios based on climate model projections. Other resources are available to support users with scenario development and climate change impact assessment.

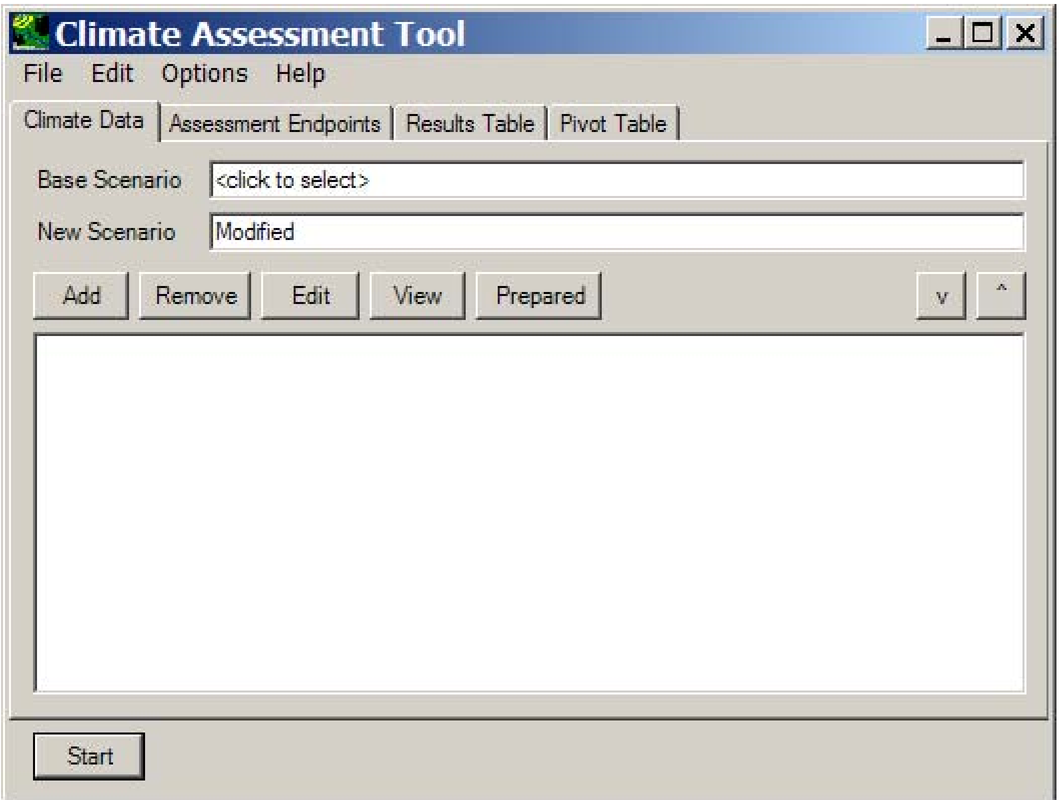
To activate CAT, first confirm that the Climate Assessment Tool is checked on the **Plug-ins:Analysis** menu on the main BASINS window.



From the main BASINS window, CAT is opened by first clicking **Analysis** on the BASINS menu bar, then **Climate Assessment Tool** on the submenu (or typing **ALT-AC**).



The main CAT window opens. It contains a menu bar, four tabs and the **Start** button.



Menu Options

On the **Climate Assessment Tool** menu, the **File** menu option includes choices to **Open a HSPF UCI file**, **Load or Save Climate and Endpoints**, **Load or Save Results**, or to **Save Pivot Table**.

The **Edit** menu option includes choices to **Copy Results**, to copy the results table, or **Copy Pivot**, to copy the pivot table. Both options allow this information to be pasted into another document (such as Word or Excel). Finally, the **Paste Results** option allows the user to paste old results (from another document) into CAT to view them in the table format, if desired.

Under the **Options** menu option, the user can choose whether only the data is copied, or whether the data and table headings are copied.

Tabs

The **Climate Data** tab allows the user to create climate change scenarios by selecting existing weather time series to be modified, and implementing one or more changes. The **Assessment Endpoints** tab allows the user to specify the hydrologic and water quality endpoints to be calculated from model output. The **Results Table** and **Pivot Table** tabs are for viewing model output including hydrologic and water quality endpoints computed by the model.

Start Button

At least one climate scenario and one assessment endpoint are necessary to run the **Climate Assessment Tool**. After selecting all climate data and endpoints desired, press the **Start** button at the bottom of the main CAT window. Further details on running CAT are provided in the Running an Assessment section.

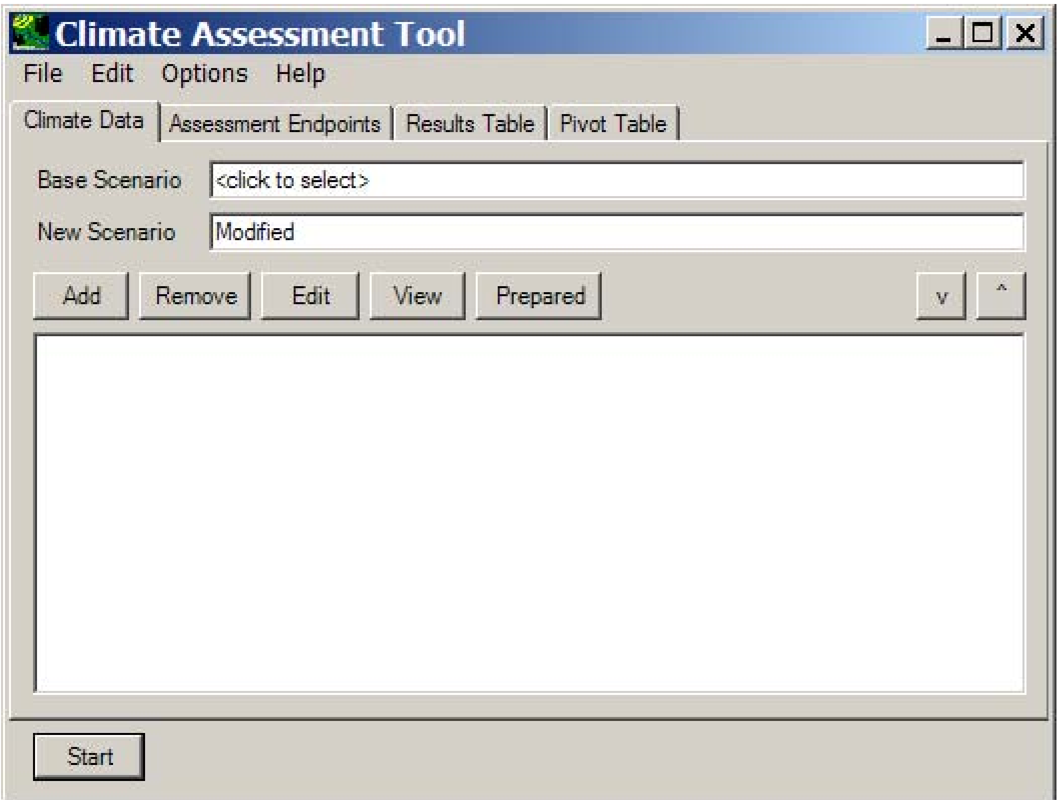
Total Iterations Selected

Once the desired climate adjustments have been specified, the **Total Iterations Selected** shown at the bottom of the window indicates the number of *HSPF* runs to complete the task. This number can range from 1 when running a single scenario, to greater than 1 when automating multiple runs using synthetic climate change scenarios to determine sensitivity to a range of different climate adjustments.

The Climate Assessment Tool makes a separate *HSPF* run for each distinct combination of input data specified by the user. After the model runs, model output endpoints for each run are displayed so that the user may analyze the impacts of varying input data. Optionally, the user may save the model output to an external file for further analysis.

A detailed tutorial is available for the Climate Assessment Tool.

4.1 Climate Data

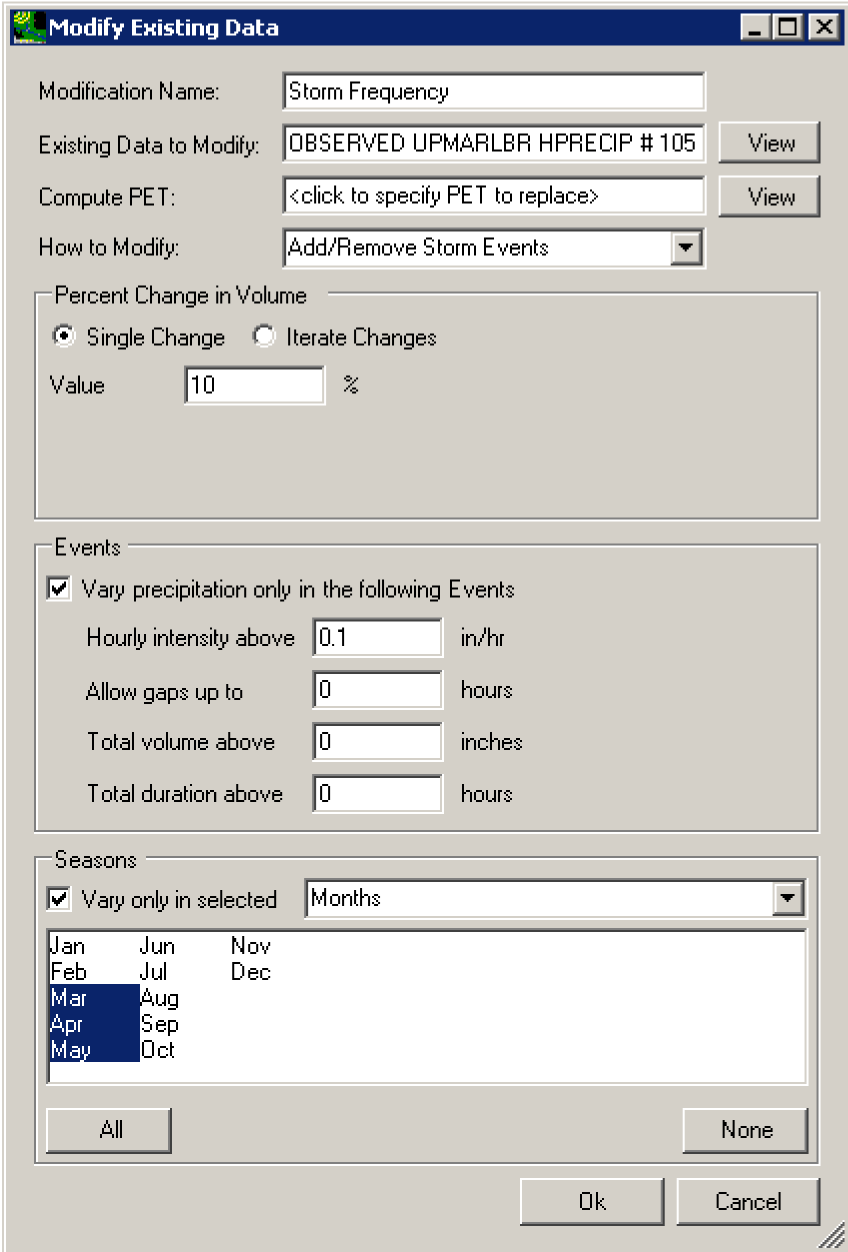


The **Climate Data** tab is the main window for managing changes to input time series data (i.e. weather data). Through this tab users are able to create climate change scenarios by selecting an existing input time series to be modified, and implementing one or more changes to create a new scenario(s).

The **Base Scenario** field contains the *HSPF* model User Control Input (UCI) file. When the model is run, a modified UCI file will be created, using the name in the **New Scenario** field as the base portion of the file name.

Add Button

Clicking the **Add** button on the **Climate Data** tab of the CAT form will display the **Modify Existing Data** form. This form contains the controls needed to define a climate adjustment, including an identification label, the dataset(s) to be modified, and how the data are to be modified. The screen shown below exhibits all features of the form.



The **Modification Name** field is used to provide a text label for identifying the scenario being created. The **Existing Data to Modify** field is used to select the historical data to which the adjustment will be made. When modifying temperature data, the **Compute PET** field is used to select the potential evapotranspiration data set that will be re-computed using the modified temperature data as input to Hamon's PET estimation method. The **How to Modify** field is a pull-down list of options for how the data are to be adjusted. The options include:

- Changing the temperature

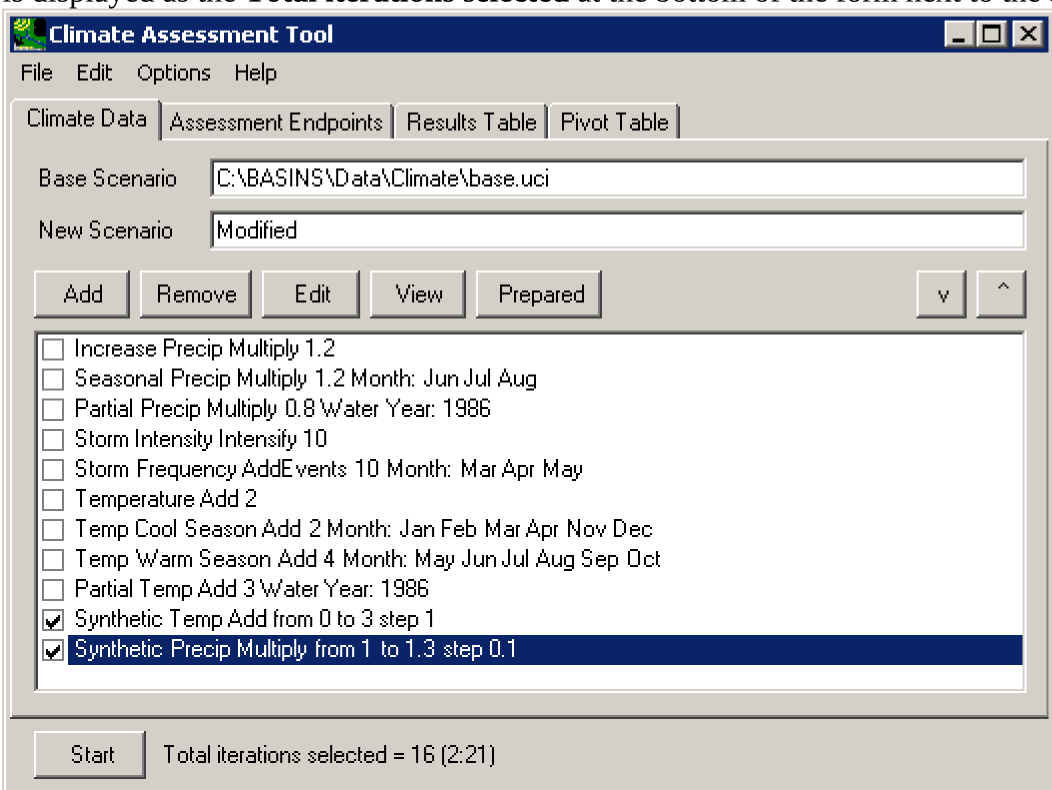
- Multiplying existing values by a number
- Adding/Removing storm events
- Adding/Removing volume in extreme events

Depending on the option selected, the frame below the **How to Modify** field is updated to input the quantity of the change (e.g. +/- degrees, % change in precipitation depth). In this frame, there are two modification options: **Single Change** or **Iterate Changes**. The term 'iterate' as used here refers to the automation of multiple runs. The **Single Change** option will result in one adjustment applied to the data set being modified. The **Iterate Changes** option will result in a range of adjustments to the data set and is used to create "synthetic" climate change scenarios. To create and run synthetic scenarios, users specify the desired type of change, the range of values to be considered, and the step interval between successive trials. For example, a user can specify an increase in average annual temperature from 0 to 3 degrees at a step interval of 1 degree (units dependent on original data set). CAT would then automate the creation and processing of four input time series (i.e. reflecting average annual temperature increases of 0, 1, 2, and 3 degrees) for input as distinct model runs. When 2 or more sets of synthetic scenarios are specified, CAT will systematically create scenarios and assess each possible combination of specified values. For example, if the above temperature change were specified together with changes in annual precipitation from 0 to 30 percent with a step interval of 10 percent (i.e. changes of 0, 10, 20, and 30%), CAT would automate the creation and processing of 4 * 4 = 16 climate change scenarios reflecting each possible combination of values.

The **Events** frame is used to define what precipitation events are considered to be storms when either Adding/Removing storm events or Adding/Removing volume in extreme events. When the **Vary precipitation only in the following Events** checkbox is selected, a set of four elements are made visible for defining storms. The **Hourly intensity above** field specifies the minimum hourly precipitation value (or series of values) that is considered to be an event. The **Allow gaps up to** field defines the number of hours allowed between two sets of storm events to consider them all one event. The **Total volume above** field specifies the minimum amount of total volume in an overall event for the event to be considered a storm. The **Total duration above** field defines the minimum number of hours of consecutive storm values for the values to be considered a storm. When Adding/Removing volume in extreme events, an additional field, **Change ... % of events**, is provided in the frame to specify the percentage of events to change. Leaving this field blank will result in the specified volume change being applied to all qualifying events. Entering a percentage value will result in the volume change being applied to the highest storms that total that percentage of the data set's volume.

The **Seasons** frame near the bottom of the form is used for specifying a time subset of the data set to which the modification will be applied. To specify a season, click on the **Vary only in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items.

As new climate adjustments are created, they are added to the text box on the **Climate Data** tab. Each new scenario can be composed of multiple adjustments to an input time series. By combining multiple adjustments, a wide range of climate change scenarios of varying complexity can be created. After adding an adjustment, it will appear as a line item in the text box below. Checking the box will apply the change to the input series when running CAT. Unchecking the box will cause the change to be ignored when running CAT. When multiple changes are applied to an input data set, the changes are implemented in the order they are listed in the text box. This order can be modified through use of the up and down arrows above the list. As adjustments are checked and unchecked, the total number of climate change scenarios is computed. This number is displayed as the **Total iterations selected** at the bottom of the form next to the **Start** button.



Remove Button

The **Remove** button is used to delete an item from the list of climate adjustments. The item to be deleted must first be highlighted before clicking the **Remove** button.

Edit Button

The **Edit** button is used to modify an existing climate adjustment. The desired adjustment must be highlighted prior to clicking the **Edit** button.

View Button

After creating an adjustment, the **View** may be used to see the actual modified data values in tabular form. The **Time series List** window will be displayed. The contents and layout of the listing may be modified through options in the **File**, **Edit**, and **View** menus. A key feature of the time series listing is the ability to export the modified values to an external file for use outside of BASINS-CAT. The **File:Save** option will save the listed data values to a tab-separated file.

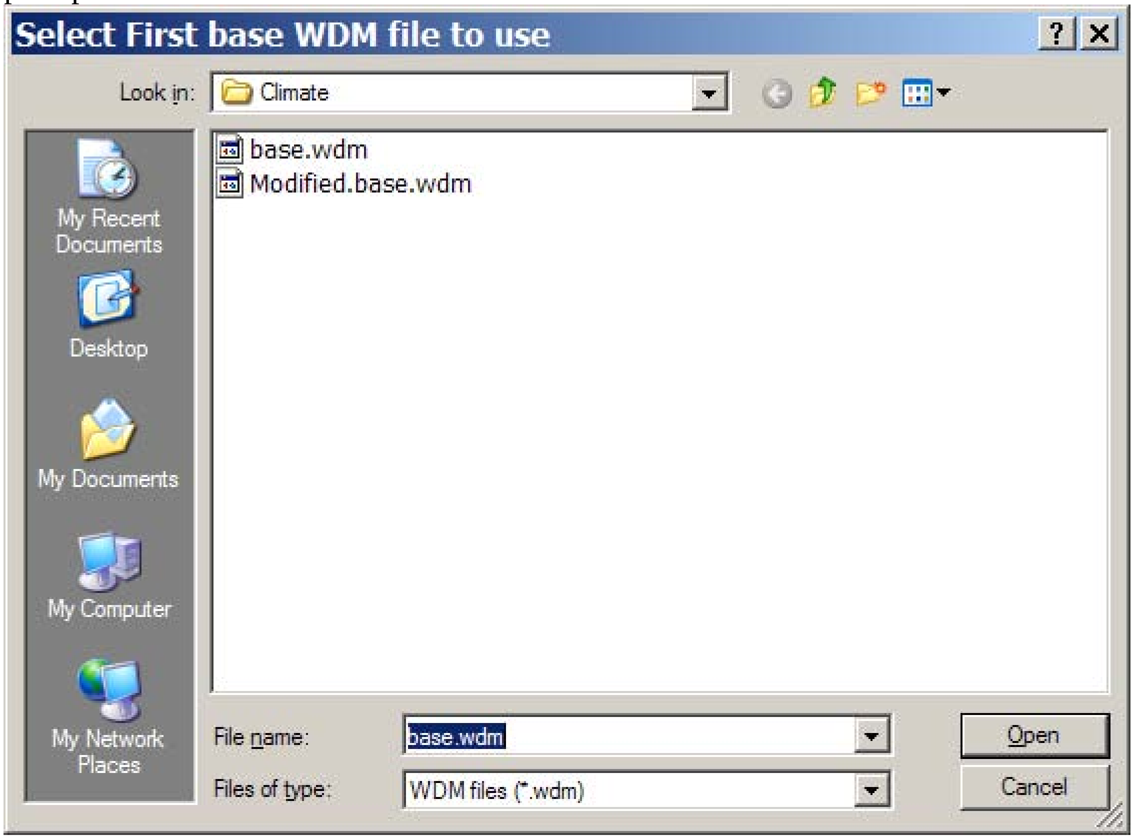
Timeseries List

File Edit View Analysis Help

History 1	from base.wdm	from base.wdm
Max	3.072	2.56
Mean	0.0057794	0.0048162
Min	0	0
1955/12/31 09:00	0	0
1955/12/31 10:00	0	0
1955/12/31 11:00	0	0
1955/12/31 12:00	0	0
1955/12/31 13:00	0	0
1955/12/31 14:00	0	0
1955/12/31 15:00	0	0
1955/12/31 16:00	0	0
1955/12/31 17:00	0	0
1955/12/31 18:00	0	0
1955/12/31 19:00	0	0
1955/12/31 20:00	0	0
1955/12/31 21:00	0	0
1955/12/31 22:00	0	0
1955/12/31 23:00	0	0
1955/12/31 24:00	0	0
1956/01/01 01:00	0	0
1956/01/01 02:00	0	0
1956/01/01 03:00	0	0
1956/01/01 04:00	0	0
1956/01/01 05:00	0	0
1956/01/01 06:00	0	0

Prepared Button

The **Prepared** button allows the user to add scenarios that have been prepared as part of a previous assessment and saved. These prepared inputs must be .WDM files, and you will be prompted to **Select First base WDM file to use**.

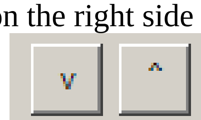


HSPF follows a certain naming convention when running CAT using prepared inputs. Select the first folder with the .WDM file prepared for the analysis. *HSPF* will go through the parallel folders that come alphabetically after that folder and add all .WDM files to CAT as prepared inputs. Therefore, the user should create parallel folders containing the relevant .WDM files, and choose the **First base WDM file** as prompted.

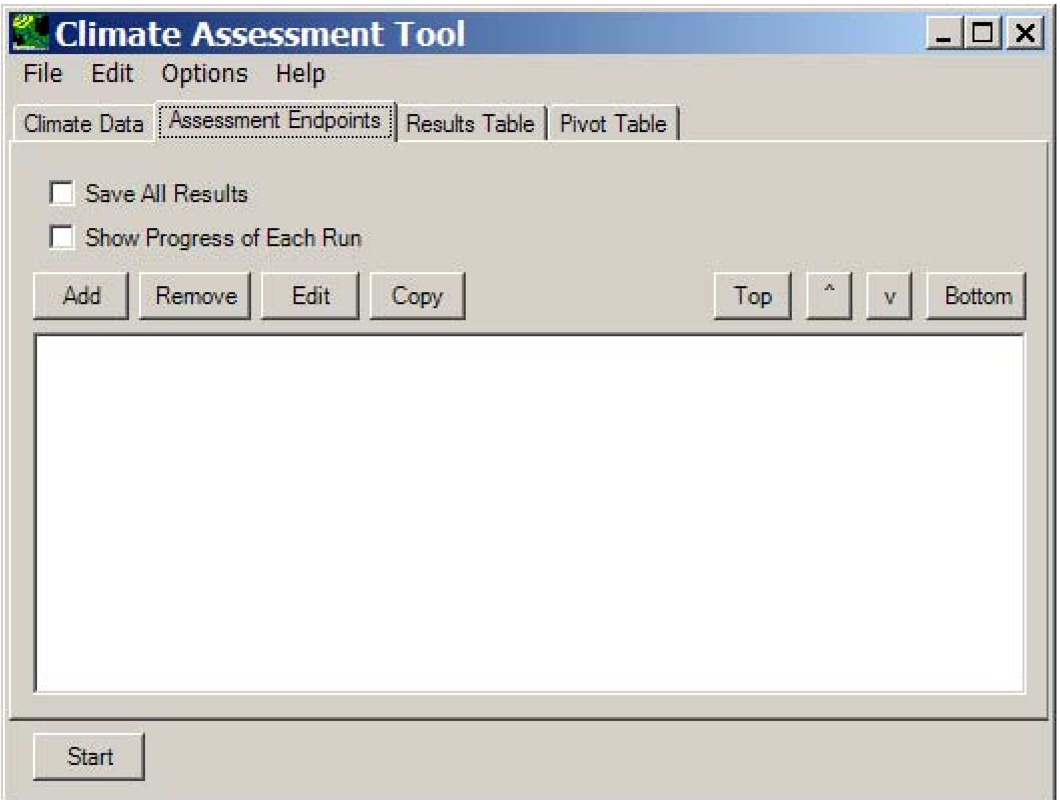
These prepared inputs cannot be edited in CAT. Instead, the benefit of running the model with prepared files is to see the effect of multiple inputs and user-selected endpoints.

While running the model using prepared data, no other (non-prepared) inputs can be used. The user must still select **Endpoints** as usual.

Arrow Buttons

The arrows on the right side of the window are used to move the list of inputs up and down for organization. 

4.2 Assessment Endpoints



EPA's Guidelines to Ecological Risk Assessment define an assessment endpoint as an explicit expression of an environmental value that is to be protected. More generally, any ecological attribute of relevance or concern to those conducting an assessment can be considered an endpoint. Examples include a particular duration-frequency flow event (e.g. the 100-year flood, 7Q10 low flow event), the annual water yield from a watershed, or the annual nutrient loading to a stream.

CAT provides a flexible capability to calculate and display assessment endpoints based on model output data. Endpoints are calculated as a post-processing step using output data. This capability allows users to quickly generate data for assessing the influence of climate change on hydrologic and water quality endpoints of concern to managers.

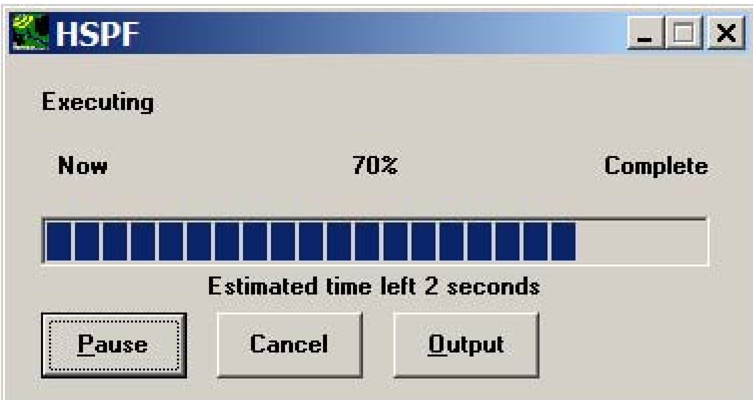
The **Assessment Endpoints** tab contains a list of the Endpoints which the user has created. To run the model, at least one climate scenario and one endpoint are necessary.

Check Boxes.

At the top of the tab window, there are two checkboxes for options when the model is run. The user can choose to:

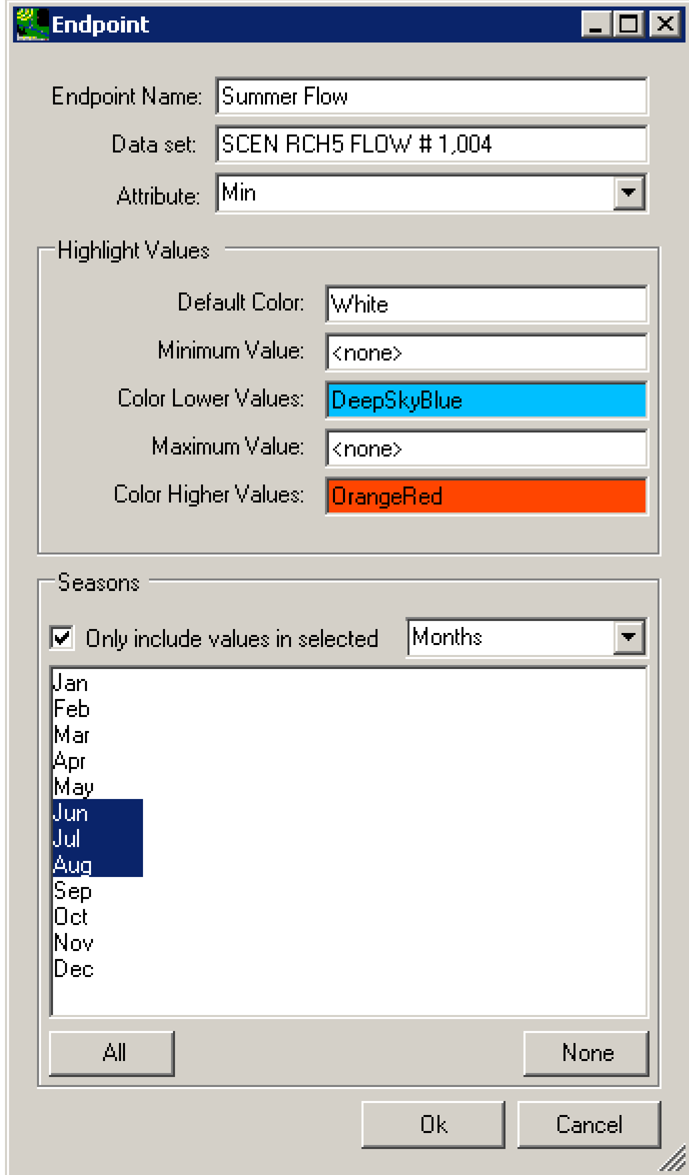
- Save all results - a new set of model inputs and outputs will be saved for each model run, using the text entered in the **New Scenario** field on the **Climate Data** tab as the base name for the new files. Index numbers will be added to file names when multiple scenarios are saved.

- Show progress of each run - the model will show a window (shown below) depicting the progress of each run. This is useful when a particularly long model is being run or a significant number of model runs is to be performed.



Add Button

Clicking the **Add** button on the **Assessment Endpoints** tab of the CAT form will display the **Endpoint** form. This form contains the controls needed to define an assessment endpoint, including the endpoint name, the dataset to be analyzed, the attribute of the dataset to be reported, value ranges of concern, and time periods of concern. The screen shown below



exhibits all features of the form.

The **Endpoint Name** field is used to provide a text label for identifying the assessment endpoint being created. The **Data set** field is used to select the model output time series from which to calculate the endpoint. The **Attribute** pull-down list contains the attributes available for selection as assessment endpoints. CAT provides a wide array of attributes, from standard statistics (e.g. mean, sum, standard deviation) to duration-frequency statistics (e.g. 7Q10, 100-year flood).

The **Highlight Values** frame allows for endpoint values of concern to be specified. A minimum and maximum range can be specified along with color codes to identify the ranges. Endpoint results within the specified range will be displayed in cells with the **Default Color** background.

Results below the **Minimum Value** will be displayed with the **Color Lower Values** background. Results above the **Maximum Value** will be displayed with the **Color Higher Values** background. Colors for all three ranges may be updated by clicking in the **color** fields.

The **Seasons** frame near the bottom of the form is used for specifying a time subset to be used when computing the endpoint value. To specify a season, click on the **Only include values in selected** check box and two additional fields will be displayed. The first field is a list of time subset options that includes **Calendar Years**, **Months**, and **Water Years**. The second field will display a list of available time intervals based on the item selected in the first field. For example, selecting **Water Years** from the first field will populate the second field with a list of available water years based on the period of record of the data set. For this example, select the **Months** option and the second field will be populated with the months of the year. Items in the second field may be selected and deselected by clicking on them. Additionally, the buttons below the list may be used to select **All** or **None** of the items.

As new endpoints are defined, they are added to the text box on the **Assessment Endpoints** tab. Endpoints in this box may be manipulated further through other buttons on this tab.

Remove Button

Click on an endpoint to highlight it, then click the **Remove** button to delete the endpoint.

Edit Button

Highlight an endpoint and click the **Edit** button to open the main **Endpoint** window to modify the endpoint.

Copy Button

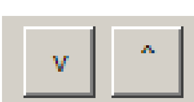
If you would like to use a similar endpoint, but make a small change (for example, change which months are selected), click the **Copy** button to create a new, identical endpoint that can be edited more easily than starting over.

Top and Bottom Buttons

These buttons are useful for organization. Highlight an endpoint, then click the **Top** button to bring the endpoint to the top of the list of endpoints on this tab. Similarly, the **Bottom** button will move a highlighted endpoint to the bottom of the list.

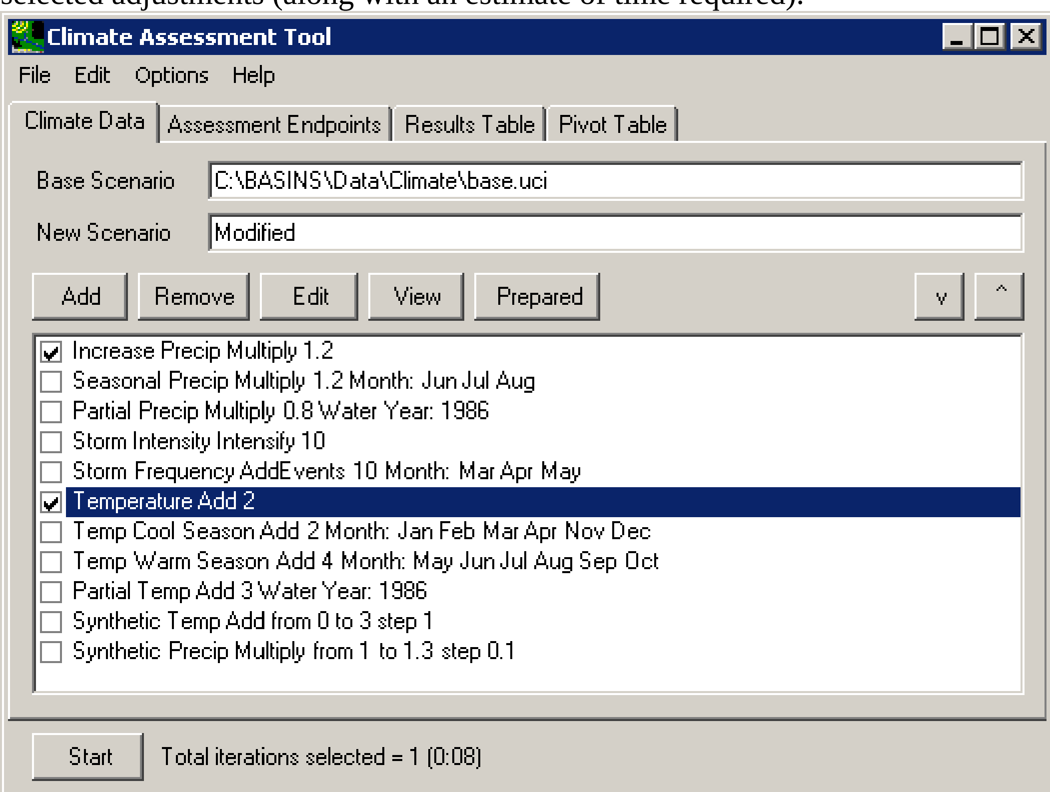
Arrow Buttons

The **Arrow** buttons on the right side of the window are used to move the list of endpoints up and down for organization.

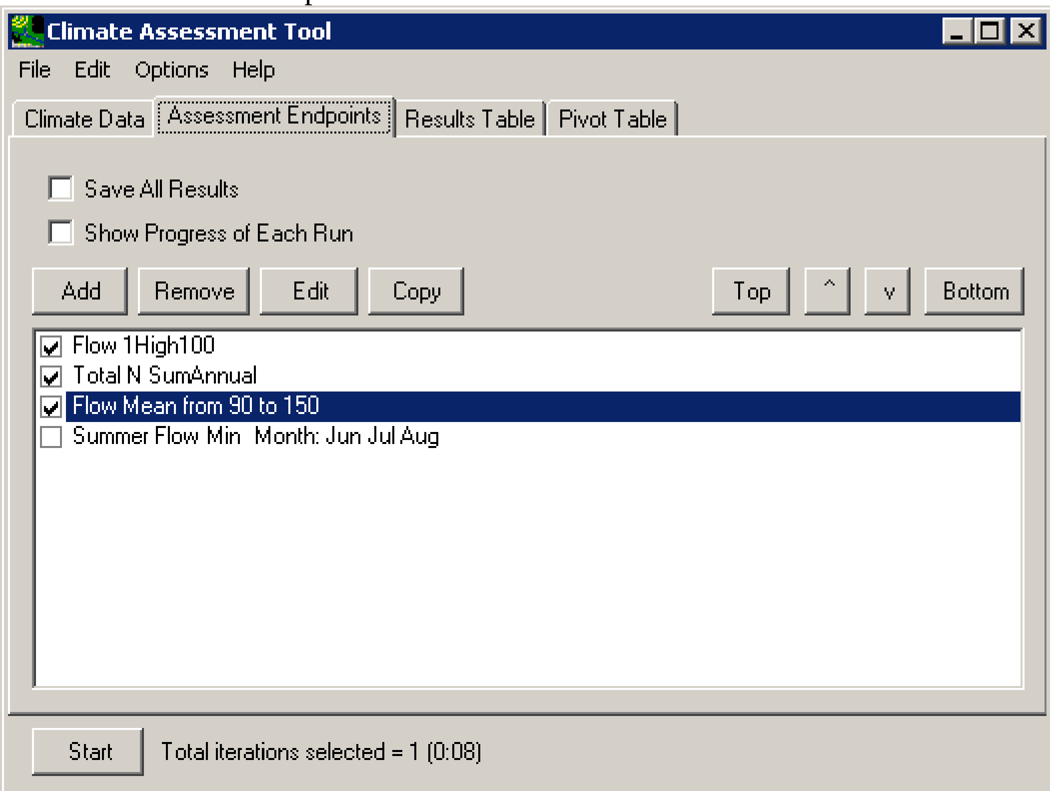


4.3 Running an Assessment

Prior to performing an assessment in CAT it is necessary to define the climate scenario(s) to be used as input to the model. The **Climate Data** tab displays a list of the previously defined climate adjustments. Each adjustment has a check box for indicating whether or not it is to be included as a component of the climate scenario being developed. The order of adjustments may be controlled by selecting an adjustment and using the up and down arrow buttons above the list. This is particularly important when multiple adjustments are being made to the same values in an input data set (e.g. increasing an entire precipitation record and also increasing a season's storm intensity). When synthetic climate change scenarios are selected for an assessment, multiple scenarios are automatically generated, resulting in multiple model runs. The **Total iterations selected** label at the bottom of the CAT form shows the number of model runs based on the selected adjustments (along with an estimate of time required).



The other step required prior to performing an assessment is selecting environmental endpoints of interest. Any number of endpoints may be selected for output from the model run(s). The **Top**, **Bottom**, and **Up/Down Arrow** buttons are useful for arranging the endpoint values in a desired order on the output results table.



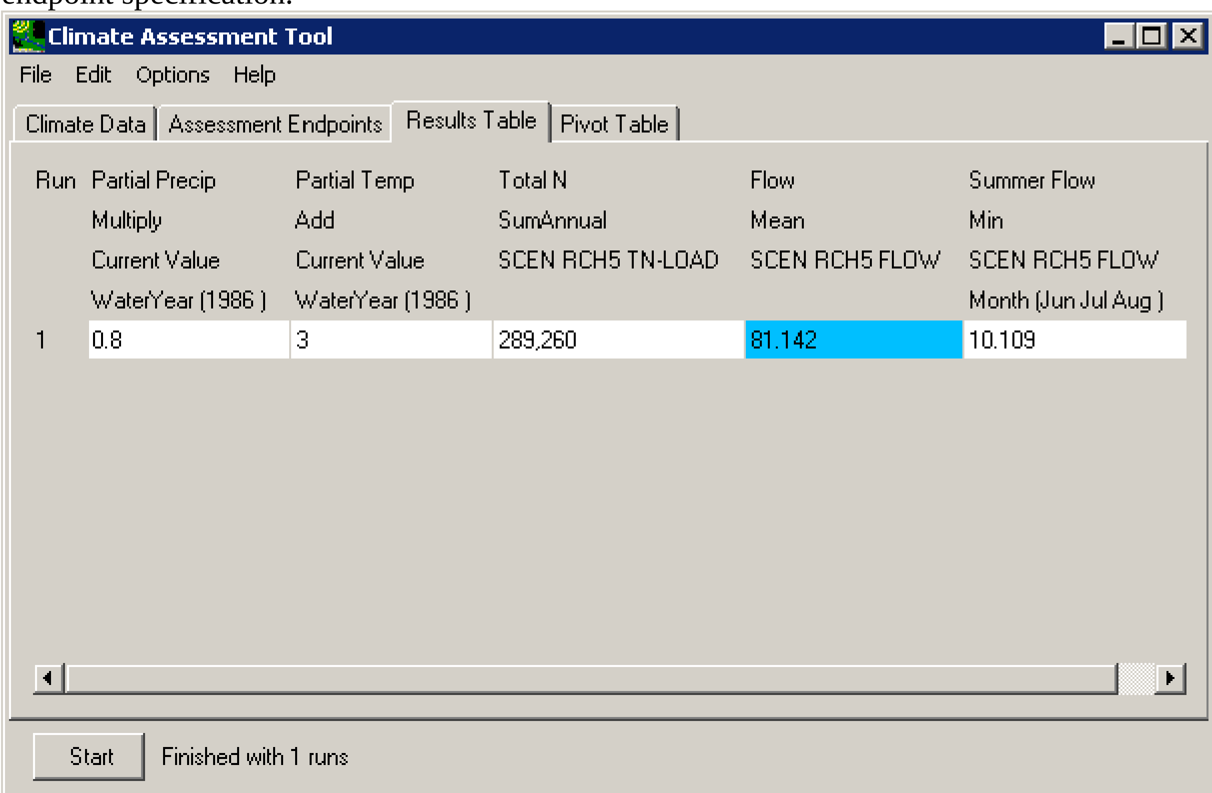
Before model execution, two additional options on the **Assessment Endpoints** tab may be set: **Save All Results** and **Show Progress of Each Run**. The **Save All Results** check box is used to set whether or not all model output is saved, not just the assessment endpoint values. Checking this box will save a new set of output results in the same manner as the original output. The text from the **New Scenario** field on the **Climate Data** tab will be used to build the base file name for the new output files. When saving multiple sets of results, this base name will also have model run number added to it. The **Show Progress of Each Run** check box is used to set whether or not a status monitor will be displayed while the model is running. If a model run is particularly long, or a series of model runs are being made using synthetic data, checking this box can be useful to see the progress of the model run(s).

4.4 Results

CAT outputs results in the form of assessment endpoint values as they are computed from model output time series. CAT results can be displayed in both a standard table and a pivot table. Additionally, it is possible to assess model output results at a greater level of detail through the main BASINS interface.

Results Table

The **Results Table** tab displays the assessment endpoint values computed from the model run's output time series. If a range of concern was specified for an endpoint and the resulting endpoint value is above or below the specified range, its background color will be set according to the endpoint specification.

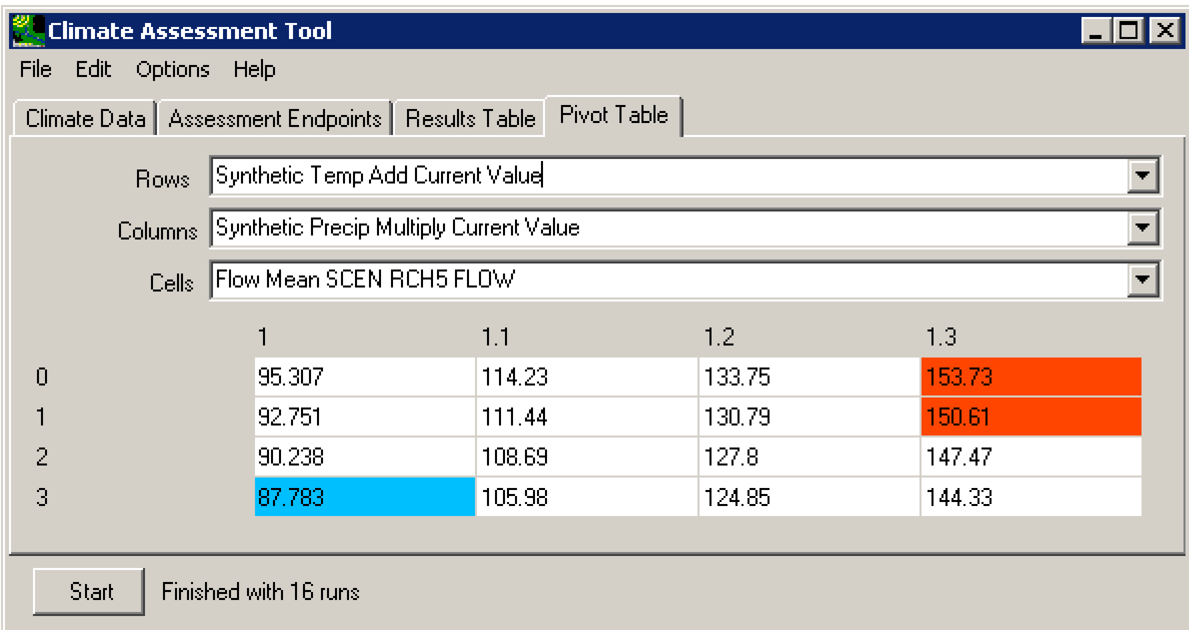


Output tables in CAT may also be saved to an external file for use outside of the program. The **Save Results** item in the **File** menu will prompt for the file name in which the results are to be saved. Results are saved in a tab-delimited format, suitable for import into Excel and other analysis programs. Additionally, the **Edit:Copy Results** menu option will copy the contents of the results table to the clipboard, making them available for pasting elsewhere.

Pivot Table

A pivot table is a data visualization and mining tool that allows users to reorganize selected columns and rows of data within a database. The term pivot refers to turning the data to view it from different perspectives. Pivot tables are especially useful for summarizing large amounts of data in a compact format, looking for patterns and relationships within a dataset, and organizing data into a format suitable for plotting data as a chart.

The **Pivot Table** tab allows users to view model output data (the same data listed in the results table) in a pivot table. The **Rows** and **Columns** fields must be selected from the dropdown lists on this tab. This feature is especially useful when synthetic climate change scenarios are used and the effects of varying climatic changes on a selected endpoint are being investigated. The first two fields of this form are used to specify what element to vary in the **Rows** and **Columns** of the pivot table. The **Cells** field is used to specify what element will be displayed in the pivot table's cells.



As with CAT's standard **Results Table**, pivot table results may also be saved to an external file. The **File:Save Pivot** option will prompt for the file name in which the pivot table is to be saved. Additionally, the **Edit:Copy Pivot** menu option will copy the contents of the pivot table to the clipboard, making them available for pasting elsewhere.

5.0 A Case Study Application of the BASINS CAT in the Monocacy River Watershed

This chapter presents a case study application of BASINS CAT assessing the potential impacts of climate change on the hydrology and water quality of a mid-Atlantic watershed. The discussion is intended to be illustrative of the type of analyses and data that can be generated using the BASINS CAT. Accordingly, we do not present a comprehensive discussion of results. A limited set of results are presented as only examples of the analyses performed. Moreover, this case study is a single example of an analysis conducted using the CAT tool. Other studies and applications of BASINS CAT may employ different methods of creating scenarios and/or address hydrologic, water quality and/or biological endpoints not discussed here.

5.1 Background and Goals

The Monocacy River flows from south-central Pennsylvania to central Maryland, and is a tributary of the Potomac River and Chesapeake Bay (Figure 5.1). During the latter half of the 20th century, human activities within the Bay watershed resulted in severe ecological impairment, principally due to nutrient pollution and associated reductions in dissolved oxygen and water clarity. To address this problem, in 1983 a government partnership called the Chesapeake Bay Program (CBP) was established among the States of Maryland, Virginia, Pennsylvania, the District of Columbia, and the federal government with the goal of restoring water quality and living resources throughout the Bay and tributaries.

This study was conducted to help the EPA Chesapeake Bay Program determine how potential future changes in climate could impact the ability to achieve nutrient and sediment reduction targets in the Monocacy River. Specifically, the study goal was to determine whether potential future climate changes by the year 2030 presented a significant risk to achieving and maintaining desired nitrogen, phosphorus, and sediment reductions. Nitrogen, phosphorus, and sediment were selected as endpoints because they have an important influence on Bay dissolved oxygen, water clarity and organisms such as crabs, fish and plankton. The planning horizon of 2030 was selected to be consistent with a concurrent CBP effort assessing the impacts of land use change on water quality. The impacts of potential future changes in land use were not considered, however, in this study.

The Monocacy watershed is 1,927 km^2 in size, with approximately 60% in agriculture, 33% forested, and 7% urban. The city of Frederick, MD, and its suburbs are the largest urban area within the watershed. The Monocacy is categorized as a Maryland Wild and Scenic River, but it has one of the greatest nonpoint source pollution problems in the state due in large part to runoff from the 3,500 farms, livestock operations and dairies in the watershed. A USGS Stream gage is located near the mouth of the river.

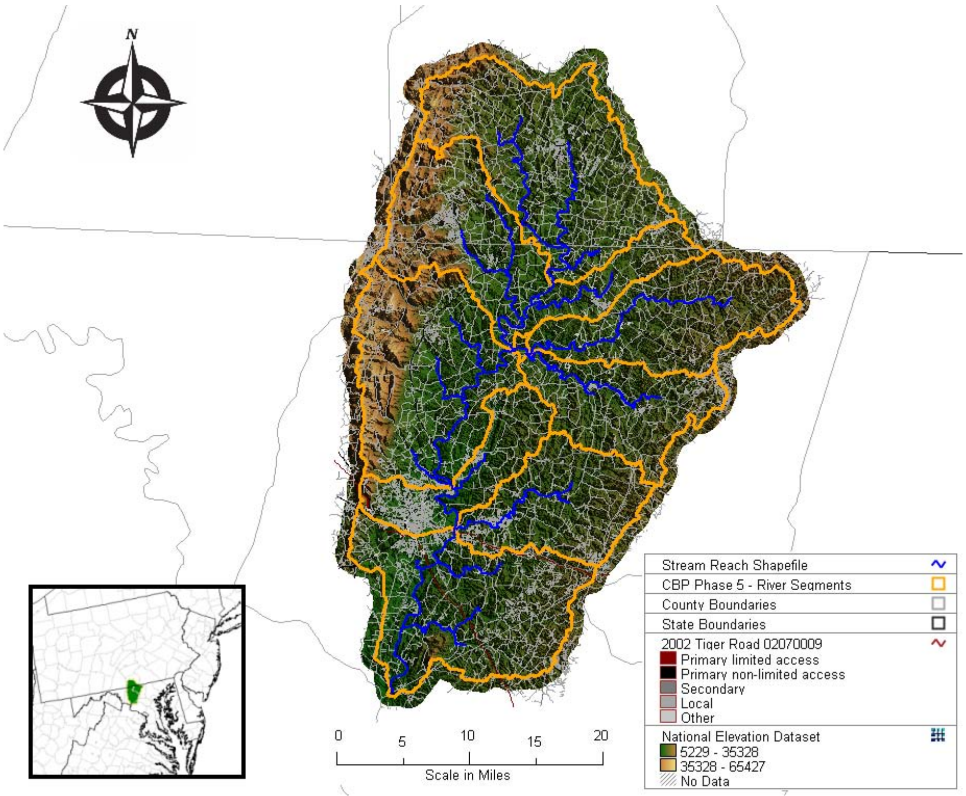


Figure 5.1. The Monocacy River Watershed.

5.2 Methods

BASINS CAT was used to create and run climate change scenarios using the watershed model HSPF. Climate change scenarios were created by modifying temperature and precipitation records for a 16 year period of historical data, from 1984 to 2000, from 7 NCDC weather stations located within or near to the watershed. As discussed previously, this approach allows scenarios to be created at multiple locations (e.g. NCDC weather stations) while maintaining the existing spatial correlation structure among neighboring locations.

The HSPF model was selected for simulating the watershed response to climate change for two reasons. First, the influence of climate change on watershed processes is complex, and it was decided that a relatively detailed model was necessary to adequately represent the sensitivities of the system to changes in temperature and precipitation. This is particularly true given the focus on the biologically reactive endpoints nitrogen and phosphorus. In addition, it was important to use a model for assessing climate change impacts that was compatible with the model used by the Chesapeake Bay Program to assess other program outcomes, the Phase 5 Community Watershed Model, which is based on HSPF. Moreover, to ensure that simulations of climate change impacts were consistent with existing Bay Program modeling practices, the Monocacy BASINS HSPF project was set up and parameterized in the same way using the same land use/landcover and BMP data as used by the Phase 5 Community Watershed Model.

5.2.1. Regional Climate Change Data

Information about future climate change in the Monocacy Watershed was acquired through Penn State University's Consortium of Atlantic Regional Assessments project (CARA) web page (http://www.cara.psu.edu/). The CARA webpage provides spatially referenced data on projected changes in temperature and precipitation totals throughout the mid-Atlantic region for the future periods 2010-2039, 2040-2069, and 2070-2099 based on climate modeling experiments using 7 GCM models from the IPCC Third Assessment Report (IPCC, 2001) and two IPCC future greenhouse gas emission storylines (A2 and B2; IPCC, 2001). CARA data are expressed as projected changes relative to the base period 1971-2000, summarized for each season of the year, and interpolated spatially from the original GCM grid resolution to 1/8 degree resolution using a spline algorithm. Collectively, climate change projections based on these 7 GCM models and A2/B2 emissions storylines capture a plausible range of future change in the Monocacy Watershed. Scenarios based on these projections, in turn, were used to identify the range of plausible changes in nitrogen, phosphorus, and sediment loads in the Monocacy River. Note that CARA website is also a good source of general information about climate change, the use of climate change scenarios for assessing impacts, land use change, and other information for the mid-Atlantic region. Additional information about the CARA data is available at: http://www.cara.psu.edu/climate/models.asp

5.2.2. Scenario Analysis

The scenarios evaluated in this study considered only potential future changes in climate. Future changes in land use, sea level rise, or other factors potentially impacting the Chesapeake Bay were not addressed. All watershed simulations thus assumed current land use conditions throughout the Monocacy watershed.

Climate change scenarios were created and analyzed in 2 ways to address different questions about system sensitivity to climate change. The first analysis used a set of "synthetic" scenarios to gain fundamental understanding of important system properties, e.g., thresholds and non-linear behaviors. Synthetic scenarios describe techniques where particular climatic attributes are changed by a realistic but arbitrary amount, often according to a qualitative interpretation of climate model simulations for a region (IPCC_TGIA, 2007). The results of this type of analysis are particularly useful for providing insights about the type and amount of change necessary to threaten a management target or push the system past a threshold. In this study, a set of 42 synthetic scenarios were created and run with the HSPF model reflecting different combinations of arbitrarily assigned changes in temperature and precipitation. Baseline temperatures were adjusted by 0, 2, 4, 6, 8, and 10°F, and baseline precipitation volume by -10, -5, 0, 5, 10, 15, and 20 percent. Changes in precipitation volume were implemented by applying a uniform multiplier to all precipitation events in the record, thus potential future increases in the proportion of precipitation occurring in larger magnitude events were not reflected in synthetic scenarios. Although the specific changes described are arbitrary, the range of temperature and precipitation change is consistent with projected changes for this region by the end of this century in the CARA dataset.

The second analysis used a set of model based climate change scenarios from the CARA database to determine the potential range of changes in nitrogen, phosphorus, and sediment loading in the Monocacy River by the year 2030. This analysis was intended to assess the sensitivity of these endpoints to a set of specific, internally consistent climate change scenarios based on climate modeling experiments reflecting different assumptions about future greenhouse gas emissions and different model representations of the climate system.

A total of 42 model-based scenarios were created and run with the HSPF model based on seasonally variable climate change projections for the period 2010-2039 (the averaging period in the CARA dataset closest to the 2030 planning horizon of the Chesapeake Bay Program) from the CARA dataset. Scenarios reflect projections based on 7 GCM models, and 2 emissions storylines, and 3 assumptions about changes in the intensity of precipitation events.

The projected changes in mean air temperature and precipitation totals for each season of the year (Dec/Jan/Feb; Mar/Apr/May; Jun/Jul/Aug; Sep/Oct/Nov) relative to the base period 1971 to 2000 were acquired for each projection in the CARA dataset. It is generally expected that as climate changes, a greater proportion of annual precipitation will occur in larger magnitude events (IPCC, 2007). The CARA dataset, however, did not provide any information about changes in precipitation intensity. Accordingly, to capture a range of plausible changes in event intensity, scenarios were created by applying projected seasonal changes from the CARA dataset in three ways: (1) as a constant multiplier applied equally to all events within the specified season, (2) as a constant multiplier applied only to the largest 30% of events within the specified season, and (3) as a constant multiplier applied only to the largest 10% of events within the specified season. The 3 assumptions about changes in precipitation intensity capture a plausible range of future changes in the distribution of precipitation among different magnitude events based on observed trends during the 20th century (e.g. during this period there was a general trend throughout the U.S. towards increases in the proportion of annual precipitation occurring in roughly the largest 30% magnitude events; Groisman et al., 2005). All totaled, the resulting set of 42 scenarios capture a broad range of plausible future climate change well suited to identifying the potential range of impacts on system endpoints.

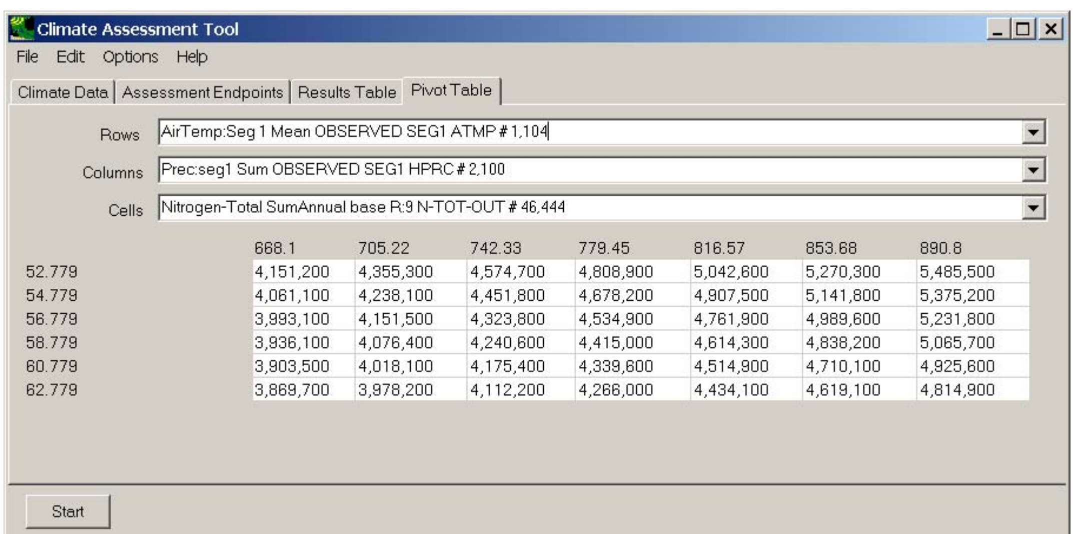
Each of the 42 scenarios was created using BASINS CAT by specifying a set of adjustments to historical temperature and precipitation time series for the period 1984 to 2000. More specifically, each scenario consisted of a set of 4 adjustments to the historical temperature time series, one for each season of the year, reflecting projected seasonal temperature changes for one projection from the CARA dataset; and 4 adjustments to the historical precipitation time series, one for each season of the year, reflecting projected seasonal precipitation changes (expressed as a percent change) together with an assumption about how changes in precipitation are distributed among different sized events (i.e. assume that the projected seasonal change in precipitation volume is distributed among all events during that season, just the largest 30% of events, or just the largest 10% of events).

5.3 Results

The model output generated by HSPF for the different scenarios evaluated can be compared, contrasted, combined, parsed, or otherwise analyzed in a great variety of ways to gain insights concerning the system response to climate change. In this study we focus on mean annual nitrogen, phosphorus, and sediment loading, although a wide range of other metrics could be calculated and assessed. As mentioned previously, the purpose of this case study is to provide an example of the types of analyses supported by BASINS CAT. Accordingly, we do not provide a detailed discussion of results or conclusions. Rather, results are presented for a single endpoint, mean annual nitrogen loading, and we provide a single graphic display of data generated using each type of scenario. Other studies and applications of BASINS CAT, depending on management/user goals, may utilize other methods of analysis and display, and may address a multitude of other hydrologic, water quality and/or biological endpoints.

5.3.1 Synthetic Scenarios

After conducting a series of HSPF simulations using BASINS CAT, a summary of results can be viewed by selecting the “Results Table” tab from the opening CAT window. This data can be exported and used with any 3rd party database, spreadsheet, or plotting package. In addition, the “Pivot Table” tab in BASINS CAT provides powerful tool for quickly exploring the response of any selected endpoint as a function of any two other variables. For example, Figure 5.2 shows in pivot table format the response of mean annual nitrogen loading in the Monocacy River to changes in mean annual temperature and precipitation based on the analysis using synthetic scenarios.



	668.1	705.22	742.33	779.45	816.57	853.68	890.8
52.779	4,151,200	4,355,300	4,574,700	4,808,900	5,042,600	5,270,300	5,485,500
54.779	4,061,100	4,238,100	4,451,800	4,678,200	4,907,500	5,141,800	5,375,200
56.779	3,993,100	4,151,500	4,323,800	4,534,900	4,761,900	4,989,600	5,231,800
58.779	3,936,100	4,076,400	4,240,600	4,415,000	4,614,300	4,838,200	5,065,700
60.779	3,903,500	4,018,100	4,175,400	4,339,600	4,514,900	4,710,100	4,925,600
62.779	3,869,700	3,978,200	4,112,200	4,266,000	4,434,100	4,619,100	4,814,900

Figure 5.2. Pivot table showing the response of mean annual nitrogen loading (pounds per year) in the Monocacy River to changes in mean annual temperature and precipitation based on the analysis using synthetic scenarios.

Figure 5.3 shows the same data contained in Figure 5.2 in a different format. The plot is based on output from 42 HSPF simulations generated using the automated (iterative) run capability of the BASINS CAT. Contours were generated by interpolation from the original 42 points, or synthetic scenarios, evaluated. The plot illustrates that as precipitation increases across the watershed, annual nitrogen loads increase, reflecting increases in runoff. As air temperature increases, annual nitrogen loads decrease in response to decreased runoff resulting from increased evapotranspiration. More specifically, the impact of warming temperatures on nitrogen loading can be seen in this figure by moving from the point labeled “current climate” vertically upwards. The impacts of changes in precipitation can be seen by moving horizontally left or right from this point. In a similar way, the projected impacts of any combination of change in temperature and precipitation on annual nitrogen loading can be seen by moving along different trajectories within the plot. Generally, mean annual nitrogen loading is shown to change about 1.1% per % change in mean annual precipitation (relative to current conditions), and about 2% per degree F change in mean annual air temperature. This type of quantitative information can be developed for any endpoint of concern, and can be useful for assessing the risk of climate change impacting a management target or goal (e.g. a target nutrient load). In this study similar plots were developed for phosphorus and sediment loading but are not shown here. It should be noted that BASINS CAT does not provide a direct capability for making contour plots such as Figure 5.3. The contour plot shown here was created using a 3rd party plotting software (DPLOT) from tabular HSPF output data generated by BASINS CAT (shown in the “Results Table” tab).

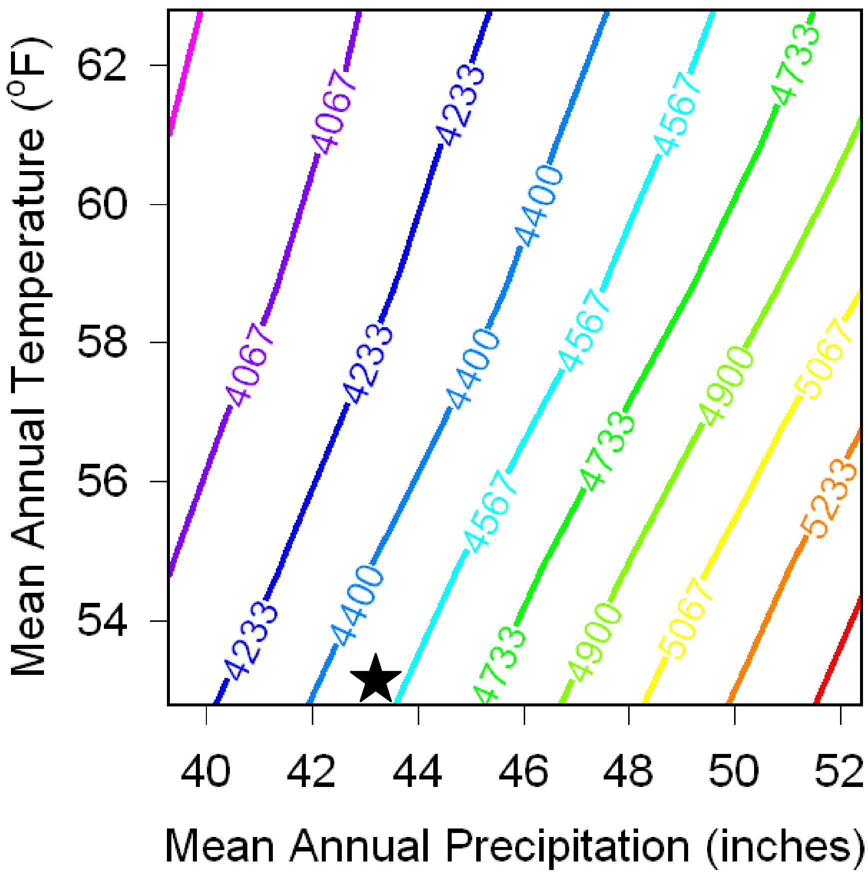


Figure 5.3. Contour plot showing the response of mean annual nitrogen loading (pounds*1000 per year) in the Monocacy River to changes in mean annual temperature and precipitation based on the analysis using synthetic scenarios. The current mean annual temperature and precipitation are indicated by the black star.

5.3.2 Model-Based Scenarios

Figure 5.4 shows the response of mean annual nitrogen loading in the Monocacy River to the model-based, seasonally variable climate change scenarios developed from climate change projection data in the CARA dataset. The data shown are from HSPF simulations of only the 14 scenarios created by applying a uniform multiplier to all events (i.e. does not reflect potential changes in the proportion of precipitation occurring in large magnitude events). BASINS CAT was used to create and run each scenario. Note that the scenarios based on other assumptions about changes in precipitation intensity have exactly the same mean annual temperature and precipitation values, and thus cannot be displayed in Figure 5.4 (because x-axis value reflects only annual total precipitation, results based on each different assumption about intensity would plot at exactly the same x,y coordinate).

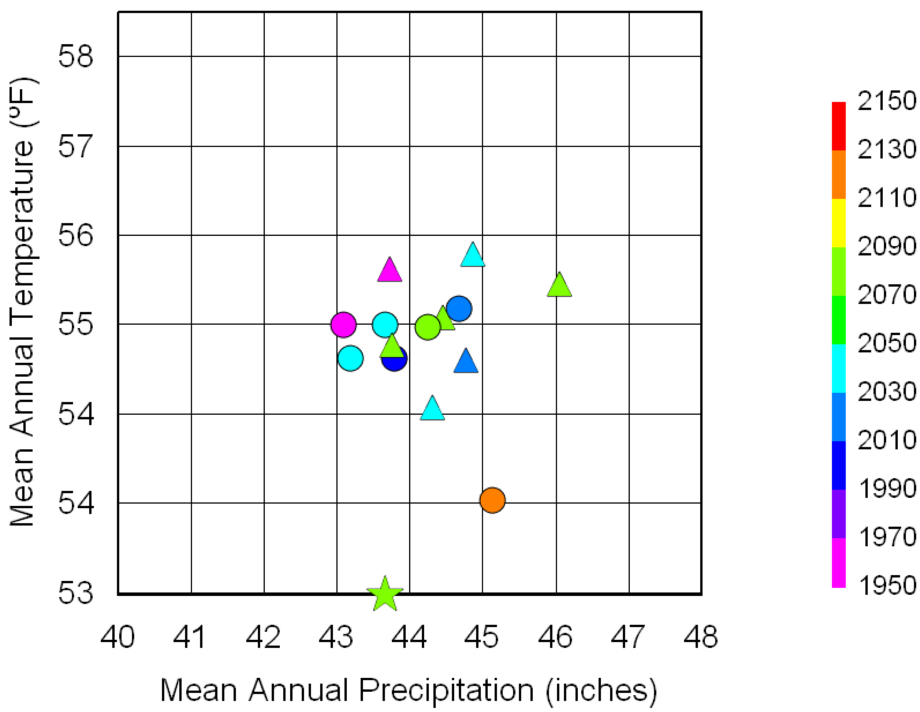


Figure 5.4. Scatter plot showing the response of mean annual nitrogen loading (indicated by the color scale in pounds*1000 per year) in the Monocacy River to model based climate change scenarios from the CARA dataset. Circles represent projections based on the A2 emissions storyline, triangles represent projections based on the B2 emissions storyline, and the star represents current mean annual temperature and precipitation.

Current climate is indicated on the plot by the star. The spatial distribution of the points shows the range of projected changes in mean annual temperature and precipitation from the 7 GCM models and two emissions storylines. All projections show warming mean annual temperatures by 2030. Projections vary with respect to changes in mean annual precipitation, with some showing increases, and others decreases. The color scale indicates the range changes in mean annual nitrogen loading in response to projected changes in climate. Changes in mean annual precipitation for these scenarios ranged from about -1 to 5 %, and changes in mean annual temperature from about 1 to 3 ^{o}F. The resulting changes in mean annual nitrogen loads ranged from about -5 to 3 %. The projected decreases are likely to result from decreases in streamflow also projected by 2030.

As with the analysis of synthetic scenarios, this type of quantitative information can be developed for various or multiple endpoints of concern, and can be useful for determining the range of potential changes in a key management target resulting from plausible future changes in climate (in this case based on model projection data). Figure 5.4 was created using a 3rd party plotting software (DPLOT) from tabular HSPF output data generated by BASINS CAT (shown in the “Results Table” tab).

5.4 Conclusions

The case study described in this chapter is a brief example of an analysis conducted using BASINS CAT assessing the sensitivity of a single water quality parameter, nitrogen, to a range of plausible changes in climate. Results suggest that nitrogen loading is sensitive to projected changes in climate in this watershed, although the direction of change is unclear due to differences in projected future changes in precipitation. Similar analyses could be conducted using the BASINS CAT tool assessing a wide range of user-specified climate change scenarios and/or hydrologic and water quality endpoints.

6.0 Other Resources

The U.S. EPA's climate change web site provides a range of information about climate change and potential climate change impacts.

http://www.epa.gov/climatechange/

The U.S. Climate Change Science Program (CCSP) web site provides links to information and products from the U.S. Global Change Research Program.

http://www.climatescience.gov/

The NOAA Climate Program Office web site provides links to information and products from NOAA.

http://www.climate.noaa.gov/cpo_pa/risa/

The Intergovernmental Panel on Climate Change (IPCC) web site provides a wealth of scientific information and products including links to the 2007 Fourth Assessment Report.

http://www.ipcc.ch/

The IPCC Task Group on Scenarios for Climate Impact Analysis gives guidance on developing scenarios and conducting climate change impact assessments.

http://ipcc-wg1.ucar.edu/wg1/wg1_tgica.html

The Consortium for Atlantic Regional Assessment (CARA) web site has a useful climate change primer along with some climate change scenarios for the Northeastern US.

http://www.cara.psu.edu/

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