Manitoba Hydro

Brandon Generating Station

Groundwater Monitoring Program 1993 – 2004

Summary of Monitoring Results

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UMA Project No.: 0217 171 01

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UMA Project No. 0217 171 01

Mr. Dave Olinyk
Environmental Licensing & Protection
Manitoba Hydro
3rd Floor - 820 Taylor Avenue
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Dear Sir:

Re: Brandon Generating Station Groundwater Monitoring Program 1993 - 2004
Summary of Monitoring Results

Please find enclosed our report for the above referenced project. If you have any questions please do not hesitate to contact our Mr. Edwin Yee at 284-0580.

Sincerely,

UMA Engineering Ltd.

Ron Typliski, P.Eng.
Regional Manager
Earth and Environmental
/dh

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1.0 Introduction

Since 1993, Manitoba Hydro has been conducting a groundwater monitoring program at the Brandon Generating Station (Brandon G.S.). The monitoring program was designed to determine if on-site activities, primarily the operation of the ash lagoon and coal stockpile area, are having an adverse effect on the groundwater quality in the area. The monitoring program was implemented as required by Clause 41(a) of Brandon GS Environment Act Licence No. 1703 R (Manitoba Environment, 1994).

This report provides a summary of the results of the monitoring conducted at this site since 1993, as well as a description of the site hydrogeology, historical operations that may have had the potential to effect groundwater quality, and an assessment of the results relative to potential impacts to groundwater. Graphical displays of the data are provided to support the discussion of the information. The detailed data and information used to prepare this report is on file at Manitoba Hydro, and regular reports of the results have been submitted to the Manitoba Conservation Regulator as part of the licence requirements.

1.1 Groundwater Monitoring Program Design

Figure 1 contains a layout of the Brandon G.S. site and the location of the fifteen observation wells used in the groundwater monitoring program.. Details of the monitoring well installations have been documented in previous reports (UMA 1995, UMA 1996). Most of the observation wells were established in 1991 and have been regularly sampled since installation. Eight observation wells (OW2, OW4, OW5, OW6, OW7, OW8, OW9 and OW10) surround the ash lagoon and four observation wells (OW11, OW12, OW13, and OW14) surround the coal storage area. Control Well OW15, installed in 1994, is located up-gradient and some distance from the ash lagoon and coal storage areas to document background conditions (UMA 1995). Wells OW1 and OW3 were taken out of service prior to 1995.

As described in the UMA reports (UMA 1995, UMA 1996), all the observation wells have been drilled to a depth of 6 to 10 meters below grade in the surficial deposits. Most of the wells were constructed using 200 mm diameter PVC casing, but wells OW12, OW13, OW14 and Control Well OW15 were constructed with smaller diameter (50 mm) PVC casings. All wells have a 1.5 m long, 0.5 mm slotted PVC pipe comprising the inlet screen at the base of the well. Consistent with normal practice, each well was backfilled with silica sand around the screened section and the boreholes were sealed with bentonite to the ground surface. The locations of each observation well relative to infrastructure of concern are summarized in Table 1.1. Detailed soil descriptions, groundwater movement rates, and pumping capacity for the wells are documented in the UMA reports (UMA 1995, UMA 1996).

Initially, the wells were monitored for water quality and water level on a monthly basis as required by Clause 41(a) of Brandon GS Environment Act Licence No. 1703 R (Manitoba Environment, 1994). In March 1997, following a review of the 1995 and 1996 reports prepared by UMA, Manitoba Environment agreed to reduce the required sampling frequency to a program of quarterly and annual measurements (Manitoba Environment, 1997). Manitoba Hydro, as required by Clause 41(c) of the Brandon GS Environment Act Licence, has submitted annual reports to the regulator (formerly Manitoba Environment, currently Manitoba Conservation) documenting the results from the groundwater monitoring program (Manitoba Environment, 1994).

Table 1.1 - Locations – Brandon GS Observation Wells

Observation Well #	Location
OW1	No longer operational
OW2	15 to 20 m outside northwest corner of current ash lagoon
OW3	No longer operational
OW4	5 to 10 m outside north side of midpoint of current ash lagoon
OW5	25 to 30 m outside north side of midpoint of current ash lagoon
OW6	15 to 20 m outside north side of east cell of current ash lagoon
OW7	15 to 20 m outside northeast corner of current ash lagoon
OW8	15 to 20 m outside east end of current ash lagoon
OW9	75 to 100 m outside of southeast corner of current ash lagoon
OW10	75 to 100 m outside south side of midpoint of current ash lagoon
OW11	75 to 100 m east of generating station, on north side of cooling tower
OW12	15 to 20 m east of coal storage pile
OW13	15 to 20 m south of coal storage pile
OW14	30 to 40 m west of coal storage pile
OW15	Control/Reference Well - west side of site, south side of access road

1.2 Background Information

The Brandon G.S. was commissioned in 1958 with four coal-fired generating units (Units 1 to 4). In 1969, a fifth coal-fired unit was added (Unit 5). Currently only Unit 5 remains in operation. The remaining four were taken out of service in 1995.

The two primary activities on the site relative to the potential to impact groundwater quality are the storage of coal on the south side of the site, and the disposal of coal ash in a lagoon at the northeast corner of the site (Figure 1). The concern with the storage of coal at this site is with the potential for precipitation infiltrating through the coal stockpile to dissolve inorganic parameters and transport the dissolved materials to the underlying groundwater. With respect to the ash lagoon, the primary concern is with the potential for precipitation to infiltrate through the ash in the inactive west lagoon cell, and dissolve inorganic constituents and transport them to the underlying groundwater. An additional concern is the potential for effluent from within the active eastern cell to infiltrate into the underlying groundwater.

Characterization of the ash lagoon effluent quality (North-South, June 2005) identified exceedances of a number of water quality parameters relative to the Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOG, Williamson 2002) for either Protection of Aquatic Life, Drinking Water, Irrigation, Livestock or Recreation. The parameters with exceedances of the MWQSOG at the point of discharge included: pH (Drinking Water); total dissolved solids (Drinking Water, Irrigation); conductivity (Irrigation); selenium (Aquatic Life, Drinking Water, Irrigation); sulphate (Drinking Water); arsenic (Drinking Water, Irrigation); boron (Irrigation); and sodium (Drinking Water). These parameters are considered the key indicator parameters of concern relative to the potential to impact groundwater quality due to their elevated presence in the ash lagoon. The assessment of the potential effects of the ash lagoon effluent discharge to the Assiniboine River found no detrimental effects (North-South, September 2006).

The potential for coal storage or the ash lagoon to impact groundwater quality is dependant on precipitation, the degree of permeability of the materials underlying the two areas, the chemistry of the materials stored in the area, and the operating procedures of the two facilities. Upgrades or changes to equipment and operating procedures that may have the potential to affect groundwater quality are listed below:

January 1996 - An electrostatic precipitator replaced the mechanical cyclone dust collectors on the plant stack, resulting in reduced air emissions and increases in ash entering the ash lagoon.

March 1996 – A closed-loop cooling tower replaced the station's once-through cooling system. Blowdown water from the cooling tower represented a new effluent stream to the ash lagoon containing elevated concentrations of dissolved solids and low concentrations of sulphuric acid and chlorine used for water treatment purposes.

1996-1997 – The station changed its fuel source to sub-bituminous coal. Chemical differences between this and the lignite coal previously used, including higher alkalinity, may have increased the pH of the ash lagoon effluent.

2000-2001 – The site water treatment plant was expanded and upgraded to provide process water for the coal-fired unit and two new combustion turbine units. No process effluents from the two new combustion turbine units are discharged to the ash lagoon.

2001 – A CO_2 injection system was installed at the ash lagoon outfall to control the pH of the ash lagoon discharge.

2003 – The ash lagoon was dredged and ash was placed in the ash pile to the west of the lagoon. The lagoon water level was raised to accommodate the ash dredging barge. The lagoon water level was raised to its maximum level in November prior to freeze-up to increase residence time and particle settling. This is the first time that the lagoon level was raised prior to freeze-up.

2004 – The north berm of the ash lagoon was stabilized in September and the water level was raised to its maximum in preparation for freeze-up.

2.0 Site Hydrogeology

2.1 Site Geology

The Brandon G.S. study area is underlain by up to 70 metres of overburden materials consisting of clay, silt, sand and gravel. The bedrock consists of carbonaceous and calcareous shales of the Vermillion River Formation, underlain by the shales of the Favel and Ashville Formations. Due to the presence of underlying low permeability shales within the Brandon area, potable supplies of groundwater cannot be developed within the bedrock and the base of the overburden sequence is considered the base of exploration for groundwater wells.

The area is located on the part of the Assiniboine River Plain physiographic region known as the Upper Assiniboine Delta. This area is at the apex of an extensive deltaic deposit formed at the time when the Assiniboine River was discharging to Glacial Lake Agassiz. As is typical of deltaic deposits, the area has been subjected to numerous erosional and depositional events that result in a complex series of paleo-channel deposits. As such, the thickness and distribution of the geologic materials varies substantially. In general, the regional overburden sequence consists of 6 to 15 metres of clay underlain by a complex sequence of interlayered sands, gravels, clays and glacial tills to the bedrock surface.

The upper 1.5 metres of the regional overburden profile has been subdivided into two general soil associations consisting of the Marringhurst Sandy Loams in the uplands and the Assiniboine Complex in the river valley lowlands (Michalyna et al, 1976).

The Marringhurst Sandy Loam soils are developed on gravel and coarse sand outwash deposits of shale, limestone and granitic origin. The surface soil texture varies from a loamy coarse sand to sandy loam, with the coarser textures predominate. The topography is level to gently undulating. The area is well drained due to the rapid infiltration rate of the coarse textured soils.

The Assiniboine Complex soils have been developed upon the alluvial deposits along the broad valley floor of the Assiniboine River. The texture of the soil varies significantly from a loamy fine sand to clay depending on the underlying parent material. Drainage varies from well drained in the coarse textured areas to poorly drained in the fine textured areas.

Within the Brandon G.S. site, the northern and northeastern parts of the site are underlain by imperfectly drained soils ranging from loamy to clayey types derived from the underlying alluvium. Permeabilities are moderately slow to slow. Within the main power plant area, the soils are primarily coarser loams derived from the underlying lacustrine deposits. Permeabilities are higher than the adjoining alluvial derived soils.

2.2 Groundwater Flow

As required by the Environment Act Licence for the Brandon GS (Manitoba Environment, 1994) and the subsequent amendment (Manitoba Environment, 1997), water levels at each observation well are regularly measured. Although quarterly sampling is currently required, water levels have been measured monthly by Manitoba Hydro.

Table 2-1 summarizes the data compiled from approximately 135 water level observations taken at each well from the 1993 to 2004. Hydrographs of the groundwater elevation measurements over this time have been compiled on Figures 2 to 4. Contour plots of groundwater elevations on selected dates have also been provided on Figures 5 to 7. This includes August 2004 (Figure 5, summer to fall conditions), May 1995 (Figure 6, major spring recharge event), and March 2002 (Figure 7, late winter conditions). Detailed data from the observation well water level monitoring program are on file at Manitoba Hydro and have been submitted to the regulators as part of the reporting requirements.

Table 2.1 - Water Levels – Brandon GS Observation Wells (1993 to 2004)

Observation Well #	Ground Elevation	Top of Pipe	Bottom of Screen	Range of Recorded Water Levels
OW2	359.07	359.28	353.58	353.78 – 357.45
OW4	357.54	357.57	349.89	353.78 – 357.54
OW5	356.99	357.21	351.66	353.29 – 356.62
OW6	357.70	358.59	351.94	354.65 – 358.40
OW7	358.18	359.32	352.85	354.82 – 357.53
OW8	357.97	359.42	354.16	355.12 – 357.56
OW9	357.88	358.85	352.70	356.10 – 357.50
OW10	358.64	359.44	353.92	356.58 – 358.18
OW11	359.46	360.16	353.90	354.90 – 357.57
OW12	359.44	360.12	353.44	352.43 – 357.00
OW13	360.06	360.87	354.01	353.70 – 359.55
OW14	360.20	361.10	354.44	356.05 – 357.24
OW15	359.38	360.15	351.80	354.50 – 357.56

Based on the review of the hydrographs and the groundwater contour plots, the following general observations are made:

- The general groundwater flow direction (Figures 5 to 7) is outwards from a groundwater high typically located in the area between the north side of the coal storage area and the southwest corner of the ash lagoon. The results suggest that this area is a zone of recharge for the local shallow groundwater. The location of the groundwater high does shift in response to seasonal changes in precipitation, but the overall flow directions do not change substantially.

- In the immediate area of the ash lagoon, groundwater flow is to the northwest and southeast from a groundwater high centered on the southwest corner of the lagoon. At times (i.e.: August 2004, Figure 5), a northeast component to the groundwater flow is also evident.

- In the immediate area of the coal storage area, groundwater flow is to the southeast to east-southeast.

- The review of the hydrographs (Figures 2 to 4) indicates that most wells respond to seasonal changes in infiltration rates. For example, a major groundwater recharge event was recorded at all wells in May, 1995. The exceptions are wells OW9 (Figure 3) and OW14 (Figure 4) which have consistently had a subdued response to seasonal changes in infiltration relative to the other wells, indicative either of a confined aquifer response or a well screen that is partially plugged. Re-development and re-testing of these wells will confirm whether the wells are fully connected to the aquifer.

- In the area of the coal storage pile (Figure 4), the relative groundwater elevation differences between the wells is generally similar, indicating the groundwater recharge and flows remain relatively consistent over time. Well OW11 does exhibit a higher level of variability, which is interpreted to be due to its proximity to the recharge area located on the north side of the coal storage area. Groundwater levels in wells OW12, OW13, and OW15 appear to have declined slightly in 2001 and remained at a lower level relative to the pre-2001 groundwater levels. The reason for this slight decline is not readily apparent, and may be related to improvements to site drainage or other minor changes to the site conditions. The groundwater levels in these three wells have been relatively stable since 2001 and no ongoing declining trend is evident.

- In the area of the ash lagoon (Figures 2 and 3), the relative groundwater elevation differences between the wells is generally similar until approximately 2000. Since 2000, the groundwater elevation at well OW6 has been generally higher than the pre-2000 levels. In 2003, the groundwater levels at well OW6 were at the highest recorded level. This coincides with the dredging of the ash lagoon and the operation of the ash lagoon at a higher level that year to accommodate the dredging barge and the change in operating procedure to maintaining a higher water level in the lagoon prior to freeze-up. Coincident with this rise in groundwater levels at well OW6, lesser rises in groundwater levels are noted at wells OW4, OW7 and to a slight degree at well OW5. There is also an apparent time delay effect in the response of groundwater levels, with groundwater levels rising first at well OW6 and then later at the other wells (i.e.: Figure 2, wells OW4 and 6). The results suggest that a reasonably strong hydraulic connection exists between the ash lagoon and the groundwater at well OW6. However, the lower permeability of the soils surrounding the ash lagoon limits the rate of movement of groundwater and results in a time delay between changes in the operation of the ash lagoon water levels and rises in groundwater levels at a distance. It is understood that since that time Manitoba Hydro assessed the ash lagoon and has placed compacted clay in lifts in the east cell to ensure the liner standards are met. These activities will limit the potential infiltration of ash lagoon water to the groundwater system.

2.3 Existing and Potential Groundwater Users

The review of the provincial Water Well Database, as well as Water Rights Licensing files indicates that there are very few existing groundwater users in the area of the Brandon G.S. The two major groundwater users in the area are Koch Fertilizer Canada Limited (formerly Simplot Chemicals) and Canexus Chemicals, southwest and southeast of the Brandon GS site, respectively. Both of these groundwater users withdraw water from a deep confined aquifer and use the water for industrial process purposes. In the case of the Koch Fertilizer groundwater supply, previous investigations have shown that the deep aquifer at that location is hydraulically connected to the alluvial sediments underlying the Assiniboine River to the west (upgradient) of the Brandon GS site. The shallow groundwater at the Brandon GS site could therefore have a small potential to be drawn into the Koch Fertilizer drawdown cone. However, given that the Brandon GS site is located downgradient of the Koch Fertilizer drawdown cone recharge zone, and that there are no significant impacts to the shallow groundwater system, the potential to affect these existing groundwater users is considered minimal. There is no known interconnection between the alluvial sediments and the Canexus drawdown cone.

Use of the shallow groundwater in the area east of the City of Brandon is minimal due to the limited available groundwater within this shallow zone and the difficulty in developing wells of sufficient capacity to meet even domestic needs. A number of domestic wells are known to be present several kilometers south of the Brandon GS site near the Highway 10 by-pass, but these wells are located topographically and hydraulically upgradient of the Brandon GS site and would not be affected by activities at the Brandon GS site.

Relative to potential future users of shallow groundwater in the Brandon GS area, the inherent difficulty of developing wells of suitable capacity from the shallow aquifer limits the future potential development of this groundwater as a drinking water source, especially in consideration of the proximity and availability of drinking water from the City of Brandon water supply system. The potential for future development of shallow groundwater as a drinking water source is therefore considered minimal.

3.0 Groundwater Quality Results

3.1 Sampling and Analysis Procedures

Water samples were collected from each well on 50 to 70 occasions (unless otherwise noted) from 1993 to 2004 and analyzed for several water quality parameters. The parameters, frequency of monitoring and reporting of results have been carried out as stipulated in the Licence Amendment Letter issued by Manitoba Conservation in March 1997 amending Clause 41(c) of the Environment Act Licence 1703 R (Manitoba Environment, 1994 and Manitoba Environment, 1997). Table 3.1 summarizes the parameters tested and the frequency.

Table 3.1 - Water Quality Parameters and Frequency

Parameter	Frequency
Total Dissolved Solids	Annual
Conductivity	Annual
pH	Quarterly
Total Hardness	Annual
Total Alkalinity	Annual
Carbonates (CO_3)	Annual
Bicarbonates (HCO_3)	Annual
Total Chlorides	Annual
Nitrates	Annual
Sulphates	Annual
Arsenic	Quarterly
Barium	Quarterly
Boron	Quarterly
Cadmium	Quarterly
Calcium	Annual
Chromium	Quarterly
Copper	Quarterly
Iron	Quarterly
Lead	Quarterly
Magnesium	Annual
Manganese	Quarterly
Nickel	Quarterly

Parameter	Frequency
Potassium	Annual
Selenium	Quarterly
Sodium	Quarterly
Zinc	Quarterly

Since 1997, concentrations of arsenic, barium, boron, cadmium, chromium, copper, iron, lead, manganese, nickel, selenium, and zinc, as well as pH levels in the observation wells have been monitored every three months. Concentrations of calcium, magnesium, potassium and sodium as well as total alkalinity, bicarbonates, carbonates, chlorides, conductivity, total dissolved solids, total hardness, nitrates, and sulphates are measured annually.

Manitoba Hydro has operated its own in-house laboratories for more than 30 years. In 1996, the Manitoba Hydro laboratories sought and received Canadian Association for Environmental Analytical Laboratories (CAEAL) accreditation for several procedures, including water analysis. The Accreditation process involved additional staff training, improved documentation of laboratory procedures and implementation of a rigorous quality assurance/quality control program and upgrades to laboratory equipment and facilities. The laboratories are required to participate in regular proficiency testing to maintain their CAEAL accreditation. Manitoba Hydro laboratories have rated very well in inter-laboratory testing programs. When the Manitoba Hydro laboratories are working to capacity, when specialized analyses are required or when independent results are necessary, samples are forwarded to other local CAEAL accredited laboratories. Laboratories that utilize different, but accepted procedures or have different detection limits as prescribed by variances in laboratory procedures and equipment, these differences are duly noted with the analysis results (Middlebrook and Morris, 2004).

Water samples are collected from the Brandon GS observation wells by Brandon GS staff following established protocols. Water samples that require filtration prior to analysis are filtered with a 0.45 µm filter in the field. Time sensitive tests (such as pH, alkalinity and chlorine) are analyzed at the well site or in the Brandon GS laboratory. Samples to be analyzed for metals are fixed with 2.5 ml of 1:1 nitric acid per 500 mL sample volume in the Brandon GS laboratory within one hour of collection. Samples are packed in coolers and shipped to the Manitoba Hydro's accredited laboratory in Selkirk for further testing within 48 hours of collection. If the Manitoba Hydro laboratory is unable to perform the analyses due to workload constraints or equipment failure, samples are forwarded to another accredited laboratory, usually ALS Laboratory Group (formerly Envirotest Laboratories).

Although Manitoba Conservation requests reporting the total concentration for most parameters (except pH, calcium, magnesium, CO_3, HCO_3, conductivity, nitrates, sodium, potassium, and boron), Manitoba Hydro's standard procedure involves filtering the sample, as this is an industry standard practice for sampling of groundwater. Unlike drinking water wells, which typically have a low suspended solids content due to regular use, monitoring wells are only pumped intermittently and can accumulate fine sediment between sampling events. Inclusion of this particulate matter in the water sample produces unrepresentative results of the true groundwater conditions as the analysis procedure measures constituents in both the solid and liquid fractions of the sample. As such, the results are usually referenced as 'dissolved' rather than total fractions. Approval for reporting of 'dissolved' results was issued in a November 2001 e-mail from Clemons Moche of Manitoba Conservation to Douglas Johnson of Manitoba Hydro.

Samples are collected, handled, analyzed and reported using accredited procedures and Quality Assurance/Quality Control practices established at Manitoba Hydro and external laboratories. Whenever possible, reference standards are analyzed with each batch of samples, including duplicates and spiked samples. Analytical results are reviewed by the analyst, validated and released by the Station Chemistry Supervisor (or delegate). Anomalous results or procedural concerns are identified in reports to management and clients. Results are documented, distributed and filed within Manitoba Hydro in electronic data management systems.

3.2 Assessment Criteria

The results of the groundwater sampling program have been assessed relative to the published Manitoba and National guidelines (Williamson 2002, CCME 2006, Health Canada 2006), in consideration of the data from the other wells sampled, and the trends in concentrations over time. The provincial and federal guidelines are collectively referred to as the Guideline in the text.

Table 3.2 lists the published numerical guidelines for the water quality parameters analyzed for the Brandon G.S. observation well water samples. The published guidelines provide numeric values for concentrations of the various parameters depending on the potential use of the groundwater and the receptor of concern. In general, the Drinking Water Guideline is the most stringent and has been applied as a conservative measure. In cases where the Freshwater Aquatic Guideline is more stringent, this value is presented in the table as well. The Manitoba Tier II Guideline values for Freshwater Aquatics cited in the table are the calculated values based on water hardness of the Assiniboine River. Wherever a 'less than the laboratory detection limit' result was reported in the analysis results, a numerical value of 50% of the detection limit has been used.

It should be noted that the national and provincial guidelines are used for initial assessment purposes only and exceedances are not to be considered to be evidence of impact to the groundwater quality as the concentrations may be naturally occurring. The guidelines are intended to be used as a benchmark for comparison of the results. Determination of whether impacts have occurred, whether remediation is required, and the level of remediation required must be done in consideration of all the site results.

Table 3.2 - Guidelines for Groundwater Quality

Parameter	Manitoba Tier II and III Guidelines*	National Guideline**
A. Standard Constituents		
Total Dissolved Solids	500,000 µg/L (3)	500,000 µg/L (10)
Conductivity	No Numerical Guideline	No Numerical Guideline
pH	6.5 – 8.5 pH units (3)	6.5 – 8.5(10)
Total Hardness	No Numerical Guideline	No Numerical Guideline
Total Alkalinity	No Numerical Guideline	No Numerical Guideline
Carbonates CO_3	No Numerical Guideline	No Numerical Guideline
Bicarbonates HCO_3	No Numerical Guideline	No Numerical Guideline
Total Chlorides	250,000 µg/L (3)	250,000 µg/L (10)
Nitrates	45,000 µg/L (1)	45,000 µg/L (8)
Sulphates	500,000 µg/L (3)	500,000 µg/L (10)
B. Trace Elements		
Arsenic	25 µg/L(2)/150 µg/L(6)	25 µg/L (9)
Barium	1,000 µg/L (1)	1,000 µg/L (8)
Boron	5,000 µg/L (2)	5,000 µg/L (9)
Cadmium	5 µg/L (1)/3.8 µg/L(6)	5 µg/L (8)
Calcium	1,000,000 µg/L (5)	No Numerical Guideline
Chromium	50 µg/L (1)/133 µg/L(6)(7)	50 µg/L (8)
Copper	1,000 µg/L (3)/17µg/L(6)	1,000 µg/L (10)
Iron	300 µg/L (3)	300 µg/L (10)
Lead	10 µg/L (1)/5.4 µg/L(6)	10 µg/L (8)
Magnesium	No Numerical Guideline	No Numerical Guideline
Manganese	50 µg/L (3)	50 µg/L (10)
Nickel	200 µg/L (4)/95 µg/L(6)	25 – 150 µg/L(11)
Potassium	No Numerical Guideline	No Numerical Guideline
Selenium	10 µg/L(1)/1 µg/L(6)	10 µg/L (8)
Sodium	200,000 µg/L (3)	200,000 µg/L (10)
Zinc	5,000 µg/L (3)/217 µg/L(6)	5,000 µg/L (10)

* Manitoba Tier II and III Guidelines as in:
Manitoba Water Quality Standards, Objectives and Guidelines, 2002
(1) Manitoba Guidelines - Drinking Water – Maximum Acceptable Concentration
(2) Manitoba Guidelines - Drinking Water – Interim Maximum Acceptable Concentration
(3) Manitoba Guidelines - Drinking Water – Aesthetic
(4) Manitoba Guidelines – Groundwater Irrigation
(5) Manitoba Guidelines – Groundwater Livestock Watering
(6) Manitoba Guidelines – Freshwater Aquatic Life (Chronic)
(7) Chromium III

** National Guidelines as in:
Guidelines for Canadian Drinking Water Quality, Health Canada, March 2006.
(8) National Guidelines – Drinking Water – Maximum Acceptable Concentration
(9) National Guidelines – Drinking Water - Interim Maximum Acceptable Concentration
(10) National Guidelines – Drinking Water – Aesthetic Objective
Canadian Water Quality Guidelines for the Protection of Aquatic Life, CCME 2006.
(11) National Guidelines – Freshwater Aquatic Life

3.3 Groundwater Quality Monitoring Results

The characterization of the ash lagoon effluent has found eight water quality parameters in excess of the MWQSOG that are considered key indicator parameters of concern relative to the potential for impact to the groundwater. For clarity, these eight parameters are discussed separately below with the results charted on Figures 8 to 37. The remaining parameters tested for as part of the groundwater monitoring program are discussed separately, and the charted results have been included in Appendix A.

3.3.1 Key Indicator Water Quality Parameters

<u>Total Dissolved Solids</u> (Figures 8 to 11)

All observation wells have Total Dissolved Solids (TDS) results in excess of the Guideline for Drinking Water of 500 mg/L over the monitoring period. TDS concentrations in wells OW11, OW12 and OW13 are approximately ten times the guideline while well OW14 shows results approximately twenty times the Guideline and well OW10 has results approximately thirty-five times the Guideline. TDS concentrations in the Control Well OW15 are also consistently above the Guideline in the 4000 mg/L range which is approximately eight times the guideline.

None of the wells except well OW10 show a particular trend of change over time. Well OW10 TDS readings appear to be declining over the most recent 3 years.

<u>Conductivity</u> (Figures 12 to 15)

There are no guidelines for conductivity. Wells OW2, OW4, OW5, OW6, OW7, OW8, OW9 and OW15 had the lowest conductivity with readings in the 1,500 to 4,000 µS/cm range. Wells OW11, OW12 and OW13 were in the 4,000 to 6,000 µS/cm range while well OW14 was approximately 8,000 to 9,000 µS/cm and readings from well OW10 were higher, mostly in the 15,000 to 17,000 µS/cm range. Control Well OW15 has background conductivity values in the 3,000 to 4,000 µS/cm range.

No trends were evident in conductivity readings, except for well 10 where conductivity appeared to be declining since 2000. This trend is consistent with a similar trend observed in the Total Dissolved Solids.

<u>pH</u> (Figures 16 to 18)

All wells, with the exception of well OW4, had pH levels within the Guideline range of 6.5 – 8.5 pH units. Well OW4 had five readings (out of 60+ samples) over a pH of 8.5 with the highest reading at 8.8. The pH values of wells OW4, OW5, OW6, OW7 and OW8 were usually higher than the values in the Control Well OW15.

There were no evident strong trends in pH levels in any wells over the monitoring period. Several wells showed groups of periodic higher or lower readings within a range of about 0.5 of a pH unit. The pH levels for Control Well OW15 appear to be slightly lower since 2001.

<u>Sulphates</u> (Figures 19 to 22)

All wells had sulphate concentrations higher than the Guideline for Drinking Water value of 500 mg/L. While concentrations in most wells were only two to three times higher than the Guideline, concentrations in well OW14 were approximately thirteen times the Guideline and twenty times the Guideline in well OW10.

Well OW10 showed a slight decrease in sulphate concentrations over the 1993/2004 period, all other wells exhibited stable patterns of concentrations. The Control Well OW15 has background sulphate concentrations in the 2,000 to 2,500 mg/L range.

<u>Arsenic</u> (Figures 23 to 26)

The Guideline for arsenic in Drinking Water is 25 µg/L. The generic National Guideline for Freshwater Aquatics is 5 µg/L and the calculated MWQSOG Guideline for Freshwater Aquatics is 150 µg/L. For the purposes of this assessment, the Drinking Water Guideline and the National Guideline for Freshwater Aquatics have been used.

Arsenic concentrations in wells OW2, OW5, OW8, OW9, OW12, OW13, and Control Well OW15 were generally lower than 10 µg/L and less than the Guideline for Drinking Water. However, some samples from wells OW4, OW6, OW7, OW11 and OW14 had a wider range of concentrations, ranging up to 30 – 40 µg/L prior to 2003 and wells OW4, OW6 and OW7, up to 90 µg/L in the 2003/2004 samples. Concentrations in samples from well OW10 varied greatly, ranging from <10 µg/L in the early 1990's to 60 µg/L in the late 1990s and 20 µg/L in 2000 and 2001 then back to <10 µg/L in 2003/2004. Arsenic concentrations in the groundwater can range from < 1 to 40 µg/L but are primarily between < 1 to 20 µg/L. Exceedances of the Guideline for Freshwater Aquatic Life (5 µg/L) have occurred in all wells but, are most common in wells OW4, OW7, OW10, OW11, OW12, OW13 and OW14.

<u>Boron</u> (Figures 27 to 29)

Boron concentrations in wells OW2, OW4 and OW5 fluctuated within the range of 3,000 to 8,000 µg/L with some samples exceeding the Guidelines for Drinking Water of 5,000 µg/L. In general, concentrations in these three wells have been higher on average since 1996/97 than measured previously. Concentrations of boron in wells OW6, OW7 and OW8 also fluctuated, ranging from 500 to 5,000 µg/L while generally declining over time. However, wells OW9, OW10, OW11, OW12, OW13, OW14 and Control Well OW15 each had consistent and lower concentrations (<1,500 µg/L), and in a narrower range (< 500 µg/L) throughout the monitoring period. (Note: The acid soluble fraction of boron has been analyzed.)

<u>Selenium</u> (Figures 30 to 33)

The Guideline for selenium in Drinking Water is 10 µg/L and the calculated MWQSOG Guideline for Freshwater Aquatics is 1 µg/L. For the purposes of this assessment, the Drinking Water Guideline and the National Guideline for Freshwater Aquatics have been used and are provided on figures. The Freshwater Aquatic Guideline of 1.0 µg/L is the detection limit for the analytical method used for most samples. Both guidelines were used to address protection of Freshwater Aquatic Life and human health.

Most samples from wells OW2, OW4, OW5, OW6, OW7, OW9, OW12, OW13, and Control Well OW15 had selenium concentrations less than the Guideline for Drinking Water. Wells OW11 and OW14 each had some samples where concentrations slightly exceeded the 10 µg/L guideline. Wells OW8 and OW10 had much higher concentrations with some values as high as 90 µg/L prior to 2002. Concentrations of selenium in well OW8 have been near or below 10 µg/L since mid 1999. Concentrations in well OW10 have also declined to the guideline since 2003. All other wells showed concentrations within a consistent range over the monitoring period.

Sodium (Figures 34 to 36)

The Guideline for sodium in Drinking Water is 200,000 µg/L. Sodium concentrations were measured from annual samples from the Brandon GS observation wells since 1997. Wells OW9, OW12 and Control Well OW15 consistently had sodium concentrations <200,000 µg/L, while wells OW2, OW4, OW5, OW6, OW7, OW8 and OW13 consistently had concentrations <500,000 µg/L. Observation wells OW11 and OW14 were < 700,000 µg/L. Well OW10 had concentrations ranging from 1,700,000 to 3,000,000 µg/L.

The only apparent trend was in well OW10 where the concentrations appeared to be decreasing over time.

3.3.2 Other Water Quality Parameters

Charts of the results for other water quality parameters have been included in Appendix A.

Total Hardness (mg $CaCO_3$/L)(Figures A.1 to A.3)

There are no guideline values for Total Hardness in drinking water. Wells OW2, OW4, OW5, OW6, OW7 and OW8 had hardness values as high as 1,600 mg/L while the hardness values in well OW9 and Control Well OW15 were approximately 2,000 mg/L and approximately 3,000 mg/L in wells OW11, OW12 and OW13. Water from wells OW10 and OW14 was much harder with readings in the 6,000 to 6,500 mg/L range.

The hardness values in all wells remained within a relatively consistent range over time except well OW10 which has declined since 2000.

Total Alkalinity, Carbonates and Bicarbonates (mg $CaCO_3$/L) (Figures A.4 to A.12)

There are no provincial or national guidelines for total alkalinity levels in drinking water. Most samples from Brandon GS observation wells OW2, OW5, OW8, OW9, OW12, OW13, and Control Well OW15 showed concentrations in the 200 to 600 mg/L range while wells OW4, OW6, and OW7 were < 200 mg/L and wells OW10, OW11 and OW14 were in the 550 to 1,000 mg/L range. Review of the carbonate and bicarbonate results shows that the total alkalinity is derived solely from bicarbonate.

Wells OW2, OW6, OW7, and OW11 showed downward trends in concentrations over the period of record while well OW15 showed consistently higher readings since 2001.

Total Chlorides (Figures A.13 to A.16)

All observation wells except well OW10 displayed total chloride levels less than or approximately equivalent to the Guideline for Drinking Water of 250 mg/L. Well OW10 had several readings eight to ten times higher than the Guideline. Concentrations in well OW10 appear to be declining over the period of record. In all other wells, the concentrations appeared to remain stable.

Nitrates [NO3(N)] (Figures A.17 to A.20)

Wells OW8, OW9 and OW12 show some nitrate concentrations in the 1993 to 1996 samples in excess of the Guideline for Drinking Water of 45 mg/L, but concentrations in all wells post-1997 are below the Guideline. This difference in the results between these sampling periods is believed to be due to changes in laboratory analytical procedures rather than any actual change in nitrate concentrations. However, the results for OW9 do show a declining trend since 2000. Nitrate levels in all other well samples were consistently much less than the Guideline.

<u>Barium</u> (Figures A.21 to A.23)

All samples had barium concentrations less than the Guideline for Drinking Water of 1000 µg/L. Most samples were < 100 µg/L, except those from well OW10, which had concentrations ranging as high as 600 µg/L. Barium concentrations in wells OW10, OW11and OW14 appear to have declined since 2001.

<u>Cadmium</u> (Figures A.24 to A.27)

Most samples from the observation wells had cadmium concentrations less than the Guideline for Drinking Water of 5 µg/L, but greater than the National Guideline for Freshwater Aquatic Life of 0.017 µg/L. The calculated MWQSOG guideline for Freshwater Aquatics is 3.8 µg/L. Concentrations in many samples were less than the detection limit. No trend over time can be identified.

<u>Calcium</u> (Figures A.28 to A.30)

Neither the Manitoba or the National Guidelines have a value for calcium in drinking water, however there is a Manitoba Guideline of 1,000,000 µg/L for groundwater used for irrigation.

Calcium concentrations varied from well to well in the eight annual samples collected since 1997 but readings were generally consistent over time in each well. Wells OW2, OW4, OW5, OW6, OW7 and OW8 all had concentrations < 100,000 µg/L. Well OW13 had concentrations between 250,000 and 350,000 µg/L while wells OW9, OW10, OW11 and OW14 had concentrations between 400,000 and 500,000 µg/L. Well OW12 had concentrations between 450,000 and 550,000 µg/L.

Concentrations in Control Well OW15 ranged from 275,000 to 350,000 µg/L between 1997 to 2000 and from 750,000 to 650,000 µg/L in the 2002, 2003 and 2004 samples.

<u>Chromium</u> (Figures A.31 to A.34)

With the exception of well OW10, all wells exhibited consistent patterns of low chromium concentrations, with most values < 20 µg/L, well under the Guideline for Drinking Water of 50 µg/L. A few higher concentrations of up to 200 µg/L recorded in the early 1990s are attributed to laboratory analytical techniques with higher minimum detection limits than those used in later years. Well OW10 exhibited a wider range of concentrations over the period of record, but most concentrations were less than the Guidelines and readings since 2001 have been consistently < 10 µg/L.

<u>Copper</u> (Figures A.35 to A.37)

Samples from all wells consistently had copper concentrations lower than the Guideline for Drinking Water of 1,000 µg/L with many sample concentrations recorded at less than the detection limit. The calculated MWQSOG guideline for Freshwater Aquatics is 17 µg/L. Wells OW2, OW4, OW5, OW6, OW7, OW8, OW9, and Control Well OW15 had most concentrations < 17 µg/L; wells OW12, OW13 and OW14 had concentrations < 60 µg/L; and wells OW10 and OW11 had values ranging from 100 µg/L to 170 µg/L. The highest readings occurred in the 1994 to 1996 period when less precise laboratory analysis procedures were in use. In general readings at all wells have been lower since 2001 but this apparent trend must be treated with caution as the laboratory detection limits have been lower since 2001. Since

2001, copper concentrations have generally been less than the National Guideline for Freshwater Aquatic Life of 2 to 4 µg/L (pH dependant).

<u>Iron</u> (Figures A.38 to A.40)

The results for some of the samples from some wells, particularly wells OW13, OW14 and Control Well OW15 had iron concentrations exceeding the Guideline for Drinking Water of 300 µg/L. Control Well OW15 had the highest concentrations of iron, and was the only well showing an apparent trend, with lower concentrations in recent years.

<u>Lead</u> (Figures A.41 to A.44)

The Guideline for Drinking Water is 10 µg/L. The National Guideline for Freshwater Aquatics is 1 to 7 µg/L (pH dependant), and the calculated MWQSOG guideline for Freshwater Aquatics is 5.4 µg/L. Lead concentrations in most of the observation well samples were below the laboratory detection limit. Stringent quality control standards established in the late 1990s have produced an improvement in the laboratory detection limit for lead. The perceived increase in lead concentrations in all wells appears to reflect the revised laboratory detection limits rather than actual higher concentrations.

No trends in lead concentrations could be confirmed because most samples were below the laboratory detection limit and these detection limits have been changed.

<u>Magnesium</u> (Figure A.45 to A.49)

There are no numerical Guidelines for magnesium concentrations in drinking water. Wells OW10 and OW14 had the highest concentrations, consistently recorded in the 1,200 mg/L range. Concentrations in wells OW11, OW12 and OW13 were approximately 700 to 400 mg/L with declining concentrations over the monitored period while all other wells, including Control Well OW15, had consistent concentrations in the 200 to 400 mg/L range.

<u>Manganese</u> (Figures A.50 to A.52)

Manganese concentrations in the Brandon GS observation wells were generally in excess of the Guideline for Drinking Water of 50 µg/L. Most wells had much higher reported concentrations in the pre-1997 period than in the 1997 to 2004 samples. Well OW12 has had highest concentration (1,000 to 2,000 µg/L with one reading nearly 4,000 µg/L) during the 1998 to 2004 period.

Two trends are evident in the manganese concentrations including lower maximum concentrations and narrower ranges of concentrations in recent years.

<u>Nickel</u> (Figures A.53 to A.55)

There is no National guideline for nickel in drinking water. The Manitoba Guideline for Drinking Water is 200 µg/L. The calculated MWQSOG guideline for Freshwater Aquatics is 95 µg/L. A few observation well samples from 1993 and 1994 had nickel concentrations in excess of the MWQSOG Freshwater Aquatics Guideline. However, the nickel concentrations in most samples from most wells in subsequent years were < 50 µg/L, although well OW10 was generally in the 50 to 100 µg/L range.

Nickel concentrations appear to be declining over time in some wells but this may be due to changes in laboratory analytical procedures and lower laboratory detection limits.

<u>Potassium</u> (Figures A.56 to A.58)

There is no guidelines for potassium concentrations in drinking water. Wells OW2, OW4, OW5, OW8, and OW9 had concentrations < 10,000 µg/L, while wells OW6, OW7, OW9, OW11, OW12, and OW13 were in the 10,000 to 20,000 µg/L range. Well OW14 had two recent readings slightly > 20,000 µg/L and well OW10 has most readings in the 30,000 to 40,000 µg/L range.

There were no definitive trends detected in the eight annual samples from any of the wells.

<u>Zinc</u> (Figures A.59 to A.61)

All wells consistently had zinc concentrations lower than the Guideline for Drinking Water of 5,000 µg/L. The calculated MWQSOG guideline for Freshwater Aquatics is 217 µg/L and the National Guideline for Freshwater Aquatic Life is 30 µg/L. With the exception of one sample period in 1994, wells OW2, OW4, OW5, OW6, OW7, OW8, OW9, OW13, and Control Well OW15 had zinc concentrations < 200 µg/L, while wells OW11, OW12 and OW14 had concentrations < 400 µg/L. Observation well OW10 had the highest readings up to 600 µg/L.

All wells displayed relatively stable patterns of zinc concentrations with no apparent increasing or decreasing trends.

3.3.3 Water Quality Parameters Sampled Prior to 1997

Mercury and silver were sampled during the initial years of the monitoring program, but were removed from the list of required parameters in 1997 (Manitoba Environment, 1997). Mercury concentrations in all wells were below the Manitoba and National drinking water guidelines of 1 ug/L (0.001 mg/L) in samples taken prior to 1997. Silver concentrations were measured in approximately 40 samples from 1993 to 1996. There are no numerical Guidelines for silver, but most of the concentrations were less than the laboratory detection limit, with the exception of the samples from wells OW10, OW11, OW13 and OW14 that were < 20 mg/L. Observation well OW10 had a few readings as high as 90 mg/L and the other wells had readings in the 30 to 60 range.

4.0 Discussion of Results

4.1 Coal Storage Area Results

The results of the groundwater level monitoring in the immediate coal storage area (Figures 5 to 7, wells OW11, OW12, OW13 and OW14) show that the groundwater flow direction is consistently to the southeast or east-southeast. Groundwater level monitoring data from off-site is not available, but it is reasonable to expect, based on the topography and regional hydrogeology of the area, that the groundwater would eventually flow to the Assiniboine River, as does all shallow groundwater within the Assiniboine River valley. From the Brandon GS site, groundwater would be expected to either follow one of the more permeable paleo-channel deposits of the Assiniboine Complex soils, or would be diverted to one of the surface drainage features which discharge to the Assiniboine River.

The review of the water quality data for the coal storage area has shown that the results have been generally consistent over the period of monitoring and in general there is no evidence that impacts to the shallow groundwater are occurring in this area. When changes to analytical methods and the normal variability of sample results are taken into consideration, the concentrations of the various parameters have been stable over the period of record, and no rising trends indicative of impacts are evident. Well OW14 has consistently had higher concentrations of total dissolved solids, conductivity, sulphate and magnesium than the other wells in the area (Figures 11, 15, 22 and A.49, respectively). However, the results have been consistent over time and the higher concentrations are likely the result of the natural mineralogy and chemistry of the specific soil horizon being monitored and not a reflection of impact. Arsenic (Figure 26) and selenium (Figure 33) have also been variable between sampling events in this well relative to the other parameters monitored but no trend is evident. The results would indicate that coal storage activities are not affecting water quality.

4.2 Ash Lagoon Area Results

The results of the groundwater level monitoring in the ash lagoon area (Figures 5 to 7, wells OW4, OW5, OW6, OW7, OW8 and OW9) show that the ash lagoon is at a groundwater flow divide, with groundwater flowing northwest, southeast and periodically to the northeast (Figure 5). The results indicate that groundwater recharge occurs in the area of the southwest corner of the lagoon and to the southwest of the lagoon and then flows laterally outwards from that groundwater high. The discharge point for groundwater flowing to the northwest and northeast from the lagoon area would be the Assiniboine River. Groundwater flow to the southeast would follow similar flow paths to those emanating from the coal storage area and would ultimately discharge to the Assiniboine River.

The monitoring of groundwater levels in the immediate area of the ash lagoon has also indicated that groundwater levels to respond to changes in the operating water level of the ash lagoon, particularly at well OW6 which appears to have a strong hydraulic connection to the lagoon. A delay in the timing of the response to lagoon water level changes at wells OW4, OW 5, and OW7 indicates that the lower permeability of the overburden soils in this area is restricting the rate the water flows through the soils.

The review of the water quality data for the ash lagoon area has found that, in general, the results have been consistent over time. The exception is the arsenic concentrations recorded since September of 2003 which have increased significantly relative to the historical concentrations at wells OW4, OW6 and OW7 and to a lesser extent at well OW5 (Figures 23, 24, and 25). This increase in arsenic concentration coincides with the observed increase in groundwater levels associated with the dredging activities in 2003 and the subsequent winter operation of the lagoon at a higher operating water level. The results are indicative of a change in site conditions associated with the dredging and/or changes in operating water levels which have resulted in an increase flux of water from the lagoon to the groundwater. However, the chemical response appears to be limited to arsenic and no corresponding trend is evident in the other lagoon effluent indicator parameters including boron (Figure 27 and 28), selenium (Figure 30, 31 and 32) and sodium (Figure 34 and 35).

Manitoba Hydro has undertaken investigations to assess the integrity of the low permeability material underlying the lagoon and has placed compacted clay within the active cell to reduce the permeability. It is recommended that in addition to these activities, additional sentry wells be installed to the north of the ash lagoon to monitor for the potential migration of contaminants from the lagoon and to allow additional information to be obtained on the groundwater flow gradients and groundwater flow rates in this area. The locations of these wells need to be confirmed in the field once access to the area is established. The preferred locations would be north of wells OW4, OW6 and OW7 and approximately halfway between the lagoon and the Assiniboine River.

It is also recommended that an additional well be installed near the southwest corner of the lagoon (an interpreted area of recharge) and to the southeast of the southwest corner of the lagoon to confirm that migration of contaminants in that direction is not occurring.

The available information indicates that the increase in arsenic concentrations are restricted to the north side of the ash lagoon. Relative to the potential for the discharge of water from the lagoon via the groundwater pathway to impact the river, it should be noted that the assessment of the potential effect of direct discharge of the ash lagoon effluent to the river found that no adverse effect was occurring (North-South, September 2006). Due to the lower permeability of the soil materials in this area, the groundwater flow rate to the river is low, and any additional contributions of groundwater to the river would be negligible relative to the direct discharge of effluent to the river. The recommended additional monitoring wells to the groundwater monitoring program are therefore considered precautionary and to further confirm that significant impacts to the river due to groundwater flow of contaminants is not occurring.

4.3 Well OW10 Results

Well OW10 is located approximately at the centre of the Brandon GS site between the coal storage area and the ash lagoon (Figure 1). The results of the water quality monitoring sampling at this well have generally found that: a) the concentrations of numerous parameters are elevated relative to the other wells in the area in particular the Control Well OW15 (Figures 10, 14, 21, 25, 28 and 32); and b) the results, particularly trace elements, are highly variable between sample events (Figure 25 and 32). It is reasonable to expect that if the well is monitoring a discrete groundwater zone and is constructed so that water from other sources (i.e.: surface water) is not being drawn into the sample, then the results should be reasonably consistent between sample events.

The observed high level of variability of the concentrations of numerous parameters between sample events suggests that the groundwater samples are perhaps being influenced by water from other surface sources or a natural level of heterogeneity in water quality associated with the mineralogy and chemistry of the soil materials. For example, samples collected during spring melt or following major precipitation events may be influenced by an influx of surface water with different chemistry than the groundwater, and may not representative of the true groundwater conditions. Replacement of the well with a new well constructed to ensure that only a discrete groundwater horizon is being sampled is recommended.

It is understood that Manitoba Hydro has installed a new well at the well OW10 location and will be monitoring the replacement well in the future. It is recommended that both the old and new OW10 wells be monitored for a period of at least one year so that the results can be compared, and a correlation established, if possible, between the new results and the historic results.

5.0 Summary and Recommendations

5.1 Summary

The following is a summary of the groundwater monitoring program at the Brandon G.S. site and the assessment of the results:

- Groundwater monitoring has been undertaken at the Brandon G.S. site since 1993. Approximately 50 to 60 samples were analyzed for 24 parameters and 8 annual samples were analyzed for 5 parameters at each of 13 observation wells (8 wells surrounding the ash lagoon, 4 wells around the coal stockpiles and 1 reference well) to 2004. Initially samples were taken on a monthly basis, but in March 1997 the sampling frequency was reduced to a quarterly cycle for some parameters and annual sampling for others.

- Piezometric elevations were measured monthly in each observation well since 1993. The general groundwater flow direction is laterally outwards from a groundwater high typically located between the north side of the coal storage area and the southwest corner of the ash lagoon. This area is interpreted to be a groundwater recharge area with groundwater flowing primarily to the northwest and southeast from this area. Groundwater flow in the immediate area of the coal storage pile is to the southeast or east-southeast. Groundwater flow in the ash lagoon area is both to the northwest and southeast from the groundwater flow divide. While most wells showed no trend in the fluctuating water levels over the period of record, three wells (OW12, OW13, and Control Well OW15) appeared to show small declines in the water table, particularly between 2002 to 2004, which may be related to minor changes in the site conditions such as improvements to the site drainage. Well OW6, on the north side of the ash lagoon, has also exhibited changes in water levels that are most likely associated with changes in the operating water level of the lagoon. Lesser fluctuations in water levels have also been noted in wells OW4 and OW7 in association with variations in lagoon operating levels. The results suggest that a reasonably strong hydraulic connection exists between the lagoon and the groundwater in the area of well OW6. All shallow groundwater flow within the river valley is either directly to the river or indirectly via the surface drainage system.

- Samples were taken from the observation wells at the stated frequency, analyzed for specified parameters and reports of results submitted to regulatory authorities as required by the Brandon GS Environment Act Licence 1703R and the subsequent amendment letter of March, 1997 from Manitoba Conservation.

- Samples were collected from the observation wells by Brandon GS staff and some time sensitive analyses were conducted at the well site or at the Brandon GS laboratory. Samples were shipped to the Selkirk GS laboratory where most analyses were conducted. When necessary, samples were forwarded to other accredited commercial laboratories for analysis. All sample handling and analyses were carried out by qualified staff using accredited methods and equipment. Quality Control and Assurance protocols were followed.

- Throughout the monitoring period, improvements have been implemented in Manitoba Hydro laboratory procedures and staff qualifications including upgraded protocols, new equipment, additional training, improved Quality Control procedures and inter-laboratory assessments.

- In recent years most of the observation well water samples have been analyzed by external laboratories, periodic duplicate tests have shown very high correlation between results from the external laboratories and the Manitoba Hydro laboratory.

- The assessment of the results of the groundwater sampling program indicates that in general, groundwater quality has not been adversely affected due to site activities. In the area of the coal storage pile, concentrations of the parameters tested for have remained relatively stable over the period of record and no evidence of a trend in declining water quality is noted. In the area of the ash lagoon, concentrations of the parameters tested for have also remained relatively stable over the period of record. The exception is the arsenic concentrations in the monitoring wells on the north side of the lagoon where concentrations have increased since 2003. This increase coincides with an increase in groundwater levels associated with dredging activities in 2003 and the subsequent operation of the lagoon at higher levels. Manitoba Hydro has undertaken investigations in 2006 to assess the integrity of the low permeability material underlying the lagoon and has placed compacted clay at the base of the lagoon to reduce permeability. Higher levels of trace elements in some of the groundwater samples were recorded in select wells. Although exceedances of the National Guideline for Freshwater Aquatics have been noted for a number of trace element parameters, adverse effects due to groundwater seepage to the river are not expected.

5.2 Recommendations

The following recommendations are made relative to future groundwater monitoring at the site:

- As part of the routine maintenance of the monitoring well network, it is recommended that the monitoring wells be re-developed and re-tested to confirm that the well screens are not becoming plugged and are still properly connected to the surrounding formation. Suggested re-development techniques include surge pumping of the wells to remove any accumulated sediments and potentially the use of surge blocks to clear the screen section of the wells. Prior to and following re-development of the wells, a response test should be conducted to measure the response of the well to changes in water levels. Any wells found to be poorly responding to changes in water levels should be replaced.

- The water level monitoring and groundwater sampling of both the new and old well OW10 should continue in parallel for at least one year to establish a correlation, if possible, between the results of the new well and the old well.

- Three new sentry wells should be installed to the north of the ash lagoon. The purpose of these wells is to obtain additional information on groundwater flow gradients and groundwater quality in this area, and to monitor any potential movement of impacted groundwater from the lagoon to the river. Monitoring and sampling of these new wells should be consistent with the existing program respecting the parameters and frequency of monitoring.

- The installation of an additional monitoring well near the southwest corner of the lagoon is recommended so that groundwater levels and chemistry can be monitored in this interpreted area of groundwater recharge. An additional sentry well should be installed to the southeast of this well to monitor the potential movement of groundwater to the southeast. Monitoring and sampling of these new wells should be consistent with the existing program.

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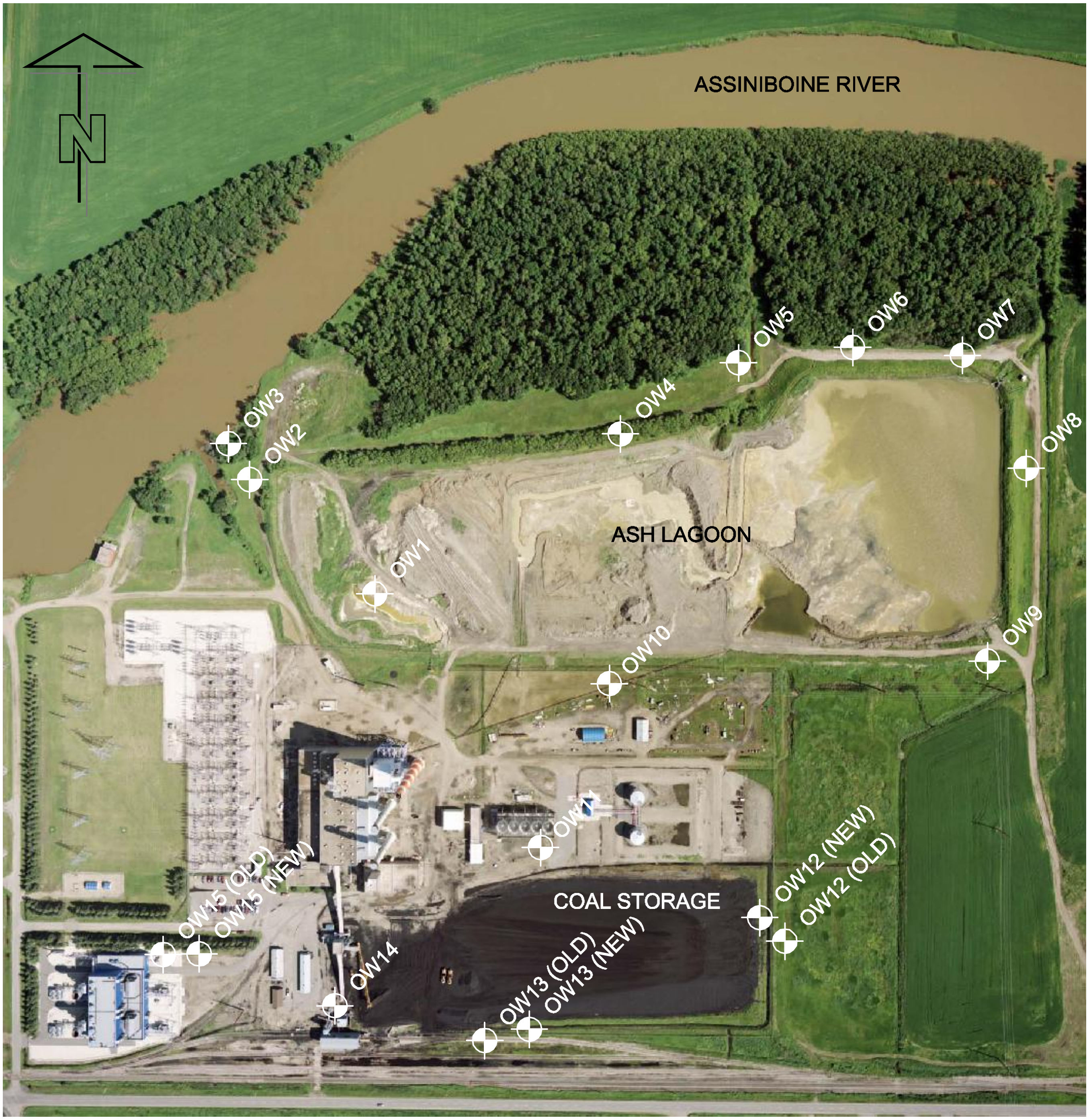
Figures



PLAN

SCALE: N.T.S.

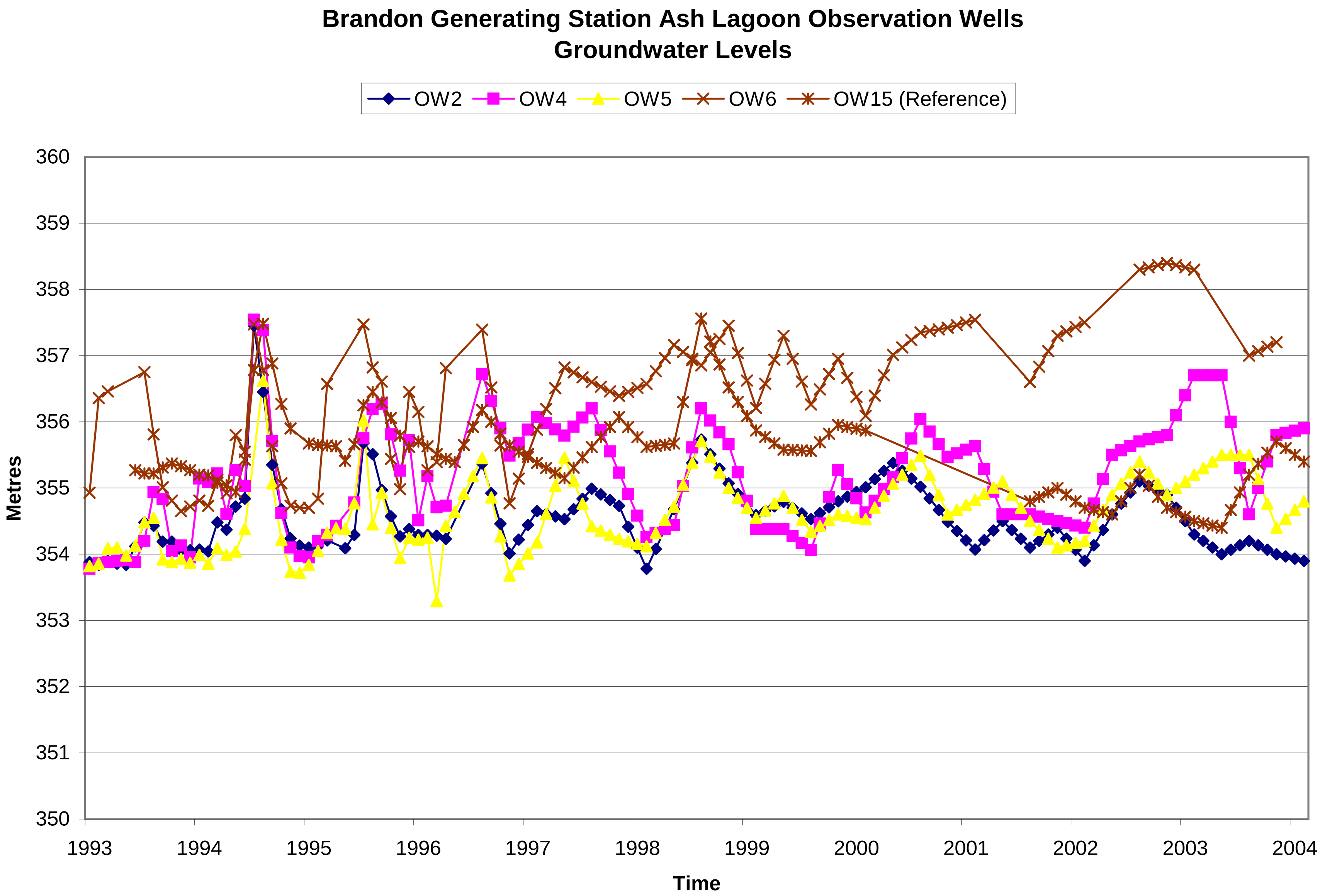
OBSERVATION WELL (OW)

Manitoba Hydro
Brandon G.S. License Review

Site Plan and Monitoring Well Locations

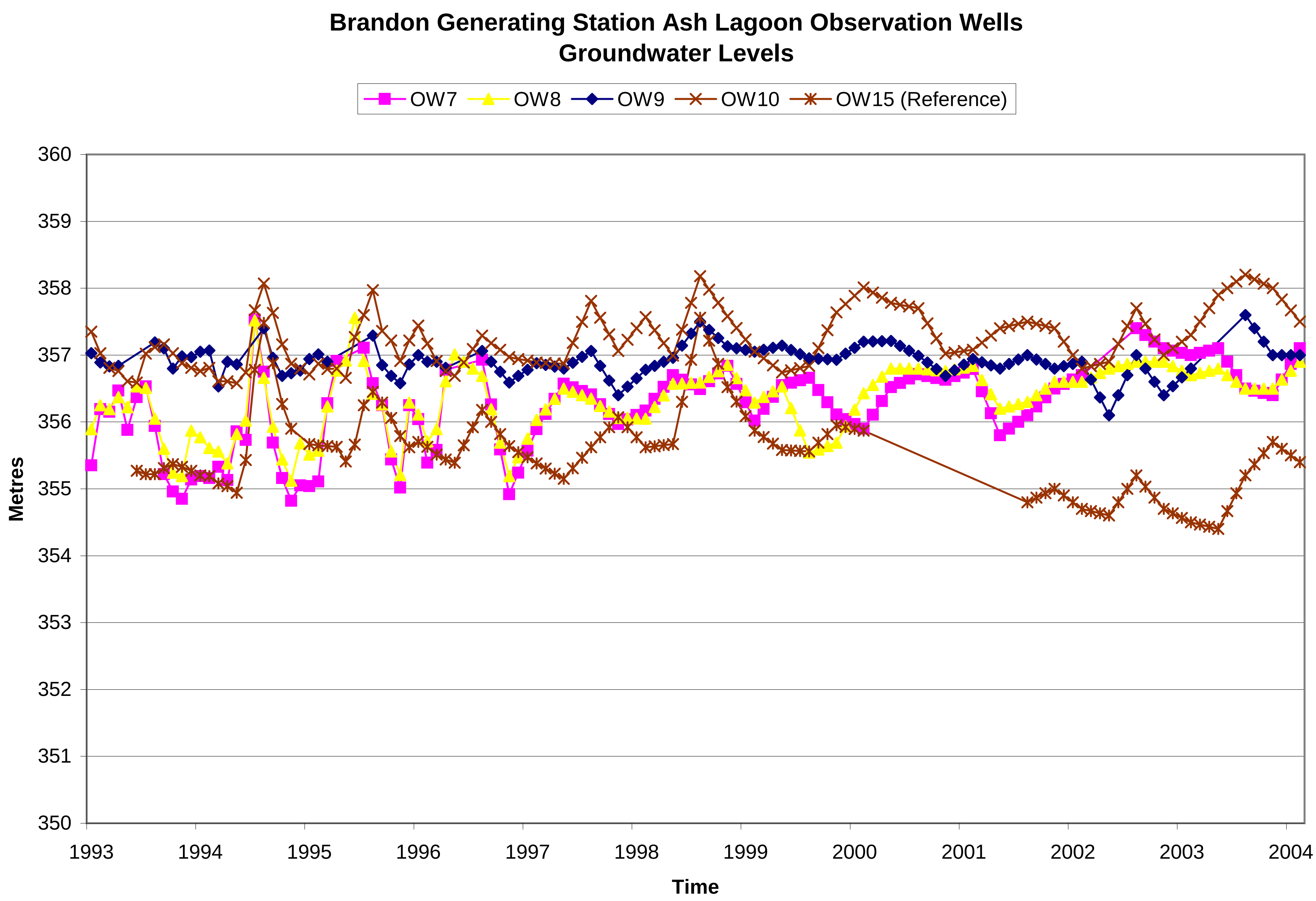
Figure - 01

UMA | AECOM



Brandon Generating Station Ash Lagoon Observation Wells
Groundwater Levels
OW2
OW4
OW5
OW6
OW15 (Reference)
Metres
360
359
358
357
356
355
354
353
352
351
350
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Time

Figure 2



Brandon Generating Station Ash Lagoon Observation Wells
Groundwater Levels
OW7
OW8
OW9
OW10
OW15 (Reference)
360
359
358
357
356
355
354
353
352
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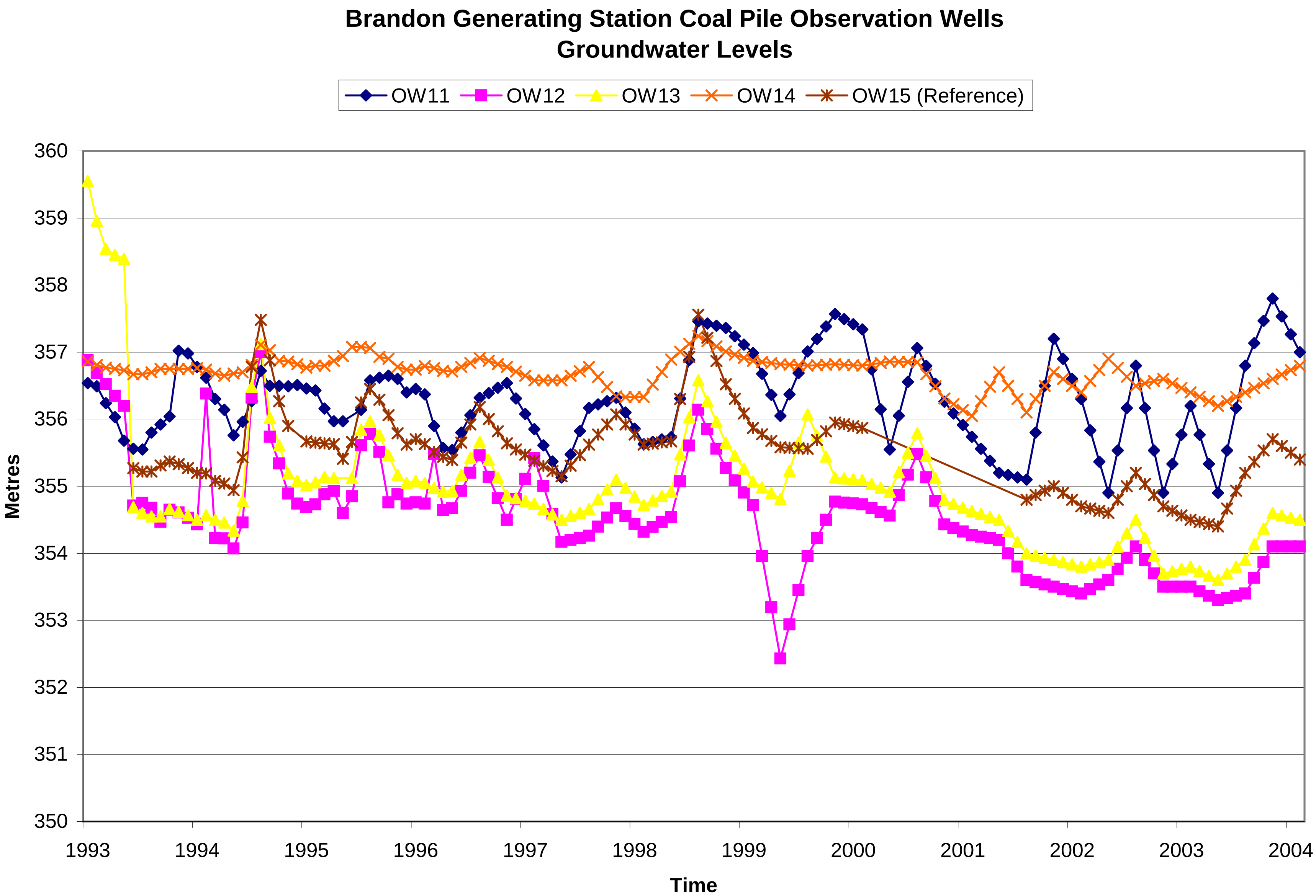
350
Metres
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Time

Figure 3


Brandon Generating Station Coal Pile Observation Wells
Groundwater Levels
OW11
OW12
OW13
OW14
OW15 (Reference)
Metres
360
359
358
357
356
355
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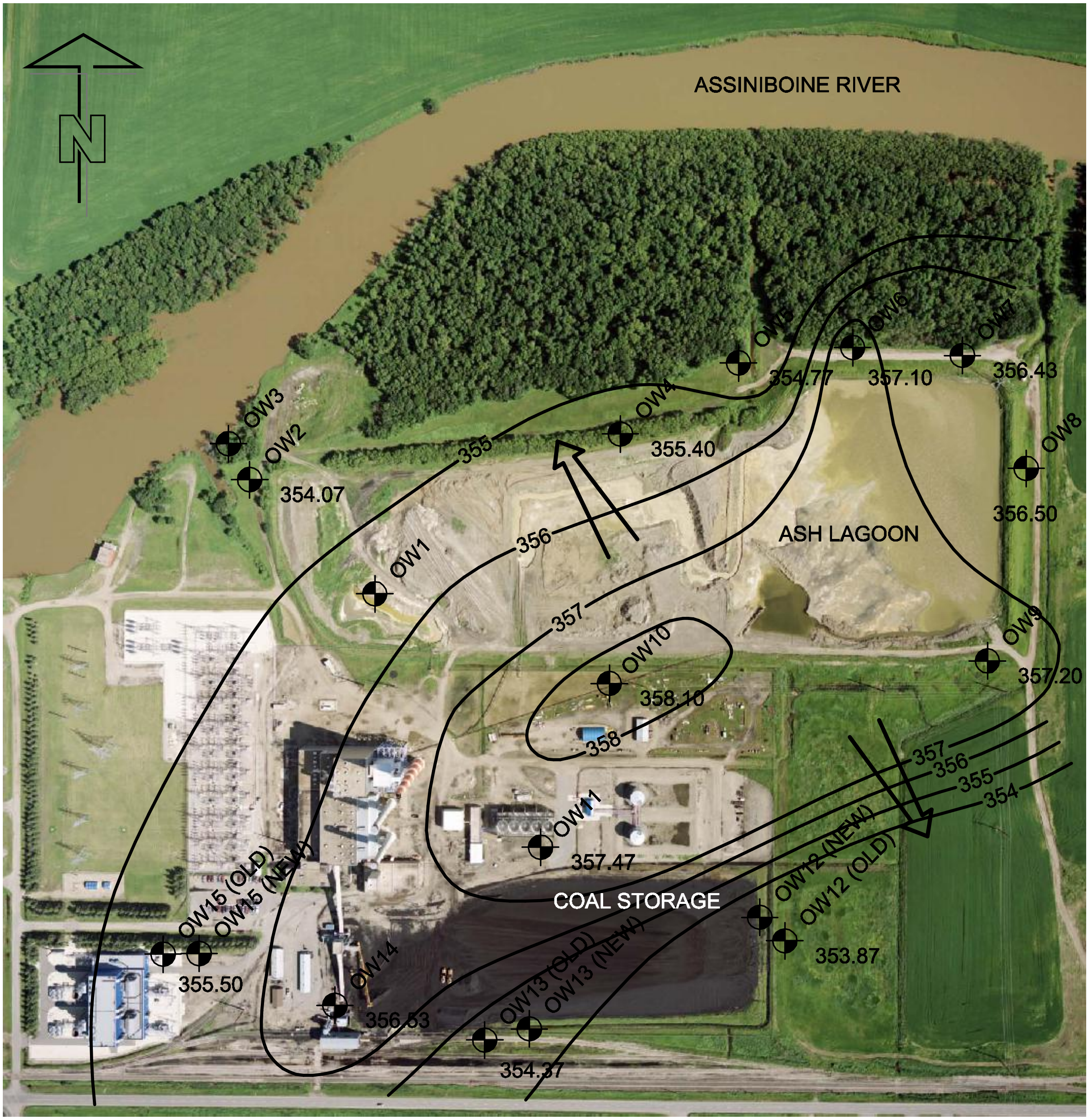
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Time

Figure 4



GROUNDWATER FLOW DIRECTION

355 GROUNDWATER CONTOUR

OBSERVATION WELL (OW)

357.54 GROUNDWATER ELEVATION (METRES)

N/A NOT AVAILABLE

Manitoba Hydro
Brandon G.S. License Review

Groundwater Elevations
August 2004
Figure - 05

PLAN

SCALE: N.T.S.

UMA | AECOM

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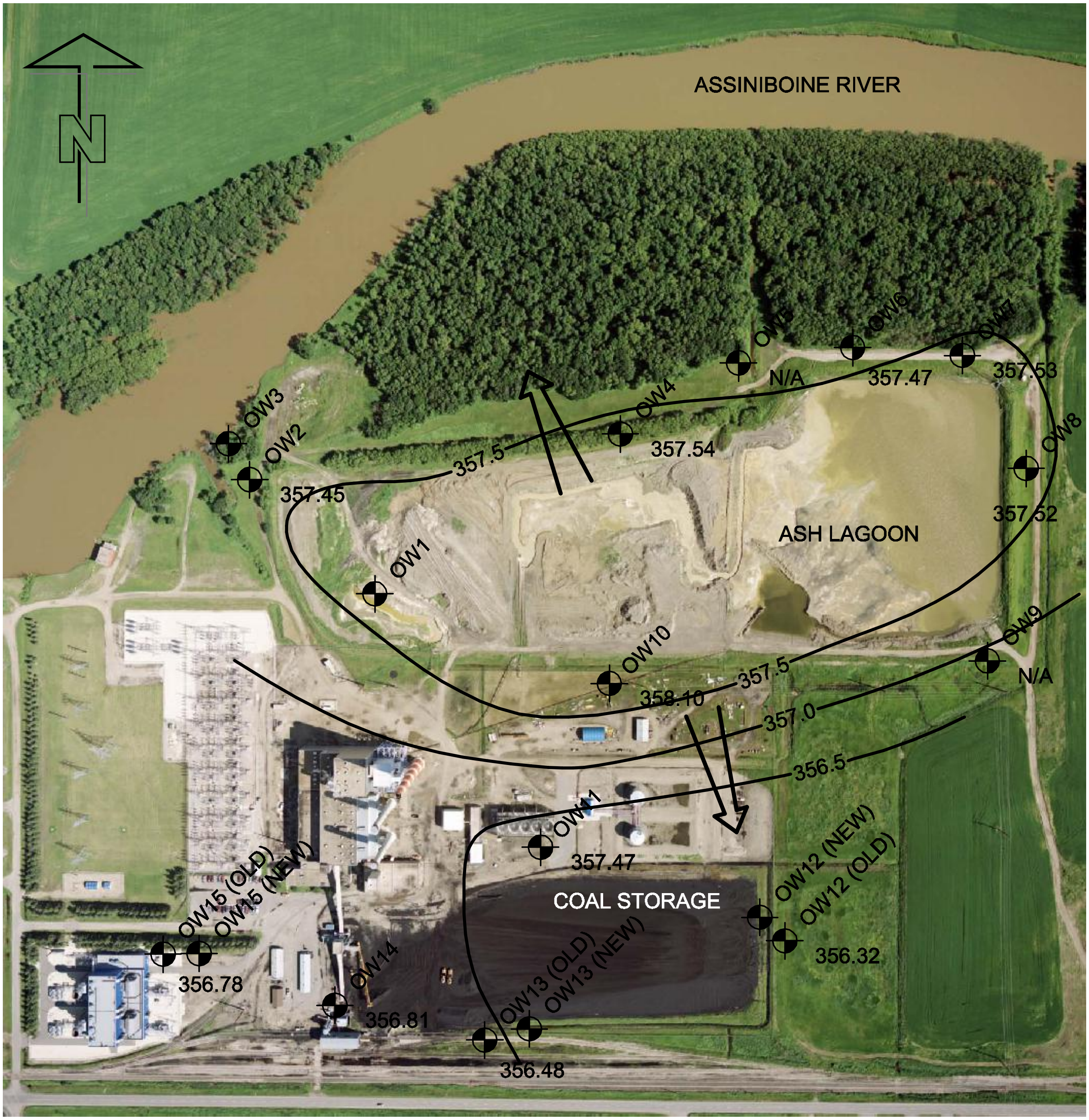


GROUNDWATER FLOW DIRECTION

357 GROUNDWATER CONTOUR

OBSERVATION WELL (OW)

357.54 GROUNDWATER ELEVATION (METRES)

N/A NOT AVAILABLE

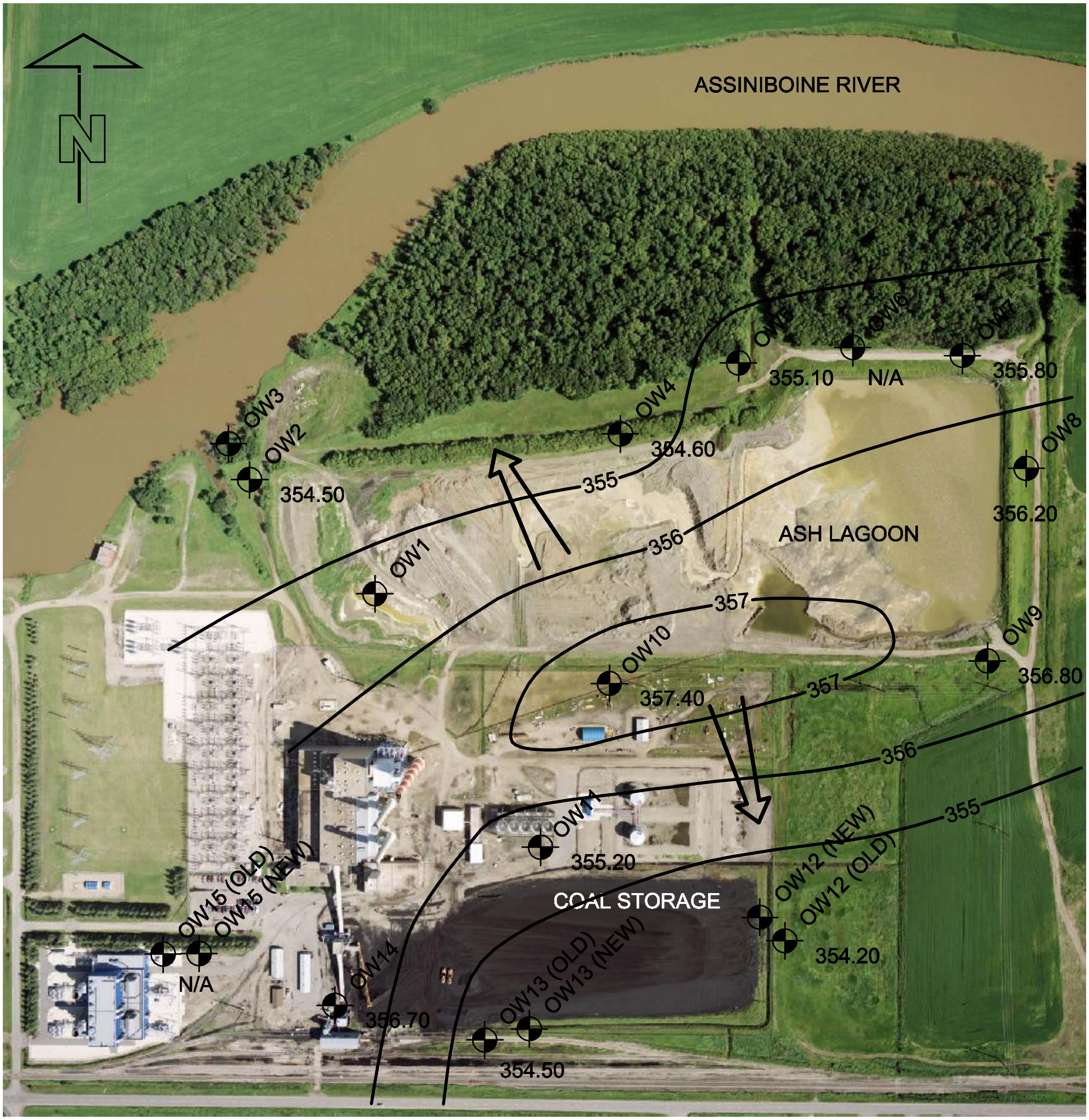
Manitoba Hydro
Brandon G.S. License Review

Groundwater Elevations
May 1995
Figure - 06

PLAN

SCALE: N.T.S.

UMA | AECOM



GROUNDWATER FLOW DIRECTION

357 GROUNDWATER CONTOUR

OBSERVATION WELL (OW)

357.40 GROUNDWATER ELEVATION (METRES)

N/A NOT AVAILABLE

Manitoba Hydro
Brandon G.S. License Review

Groundwater Elevations
March 2002
Figure - 07

PLAN
SCALE: N.T.S.

UMA | AECOM

UMA FILE NAME: 0217-171-01_01-H-F007_RX_recover.dwg Saved By: mhadfiel PLOT: 06-10-24 10:45:38 AM A SIZE 8.5" x 11" (215.9mm x 279.4mm)

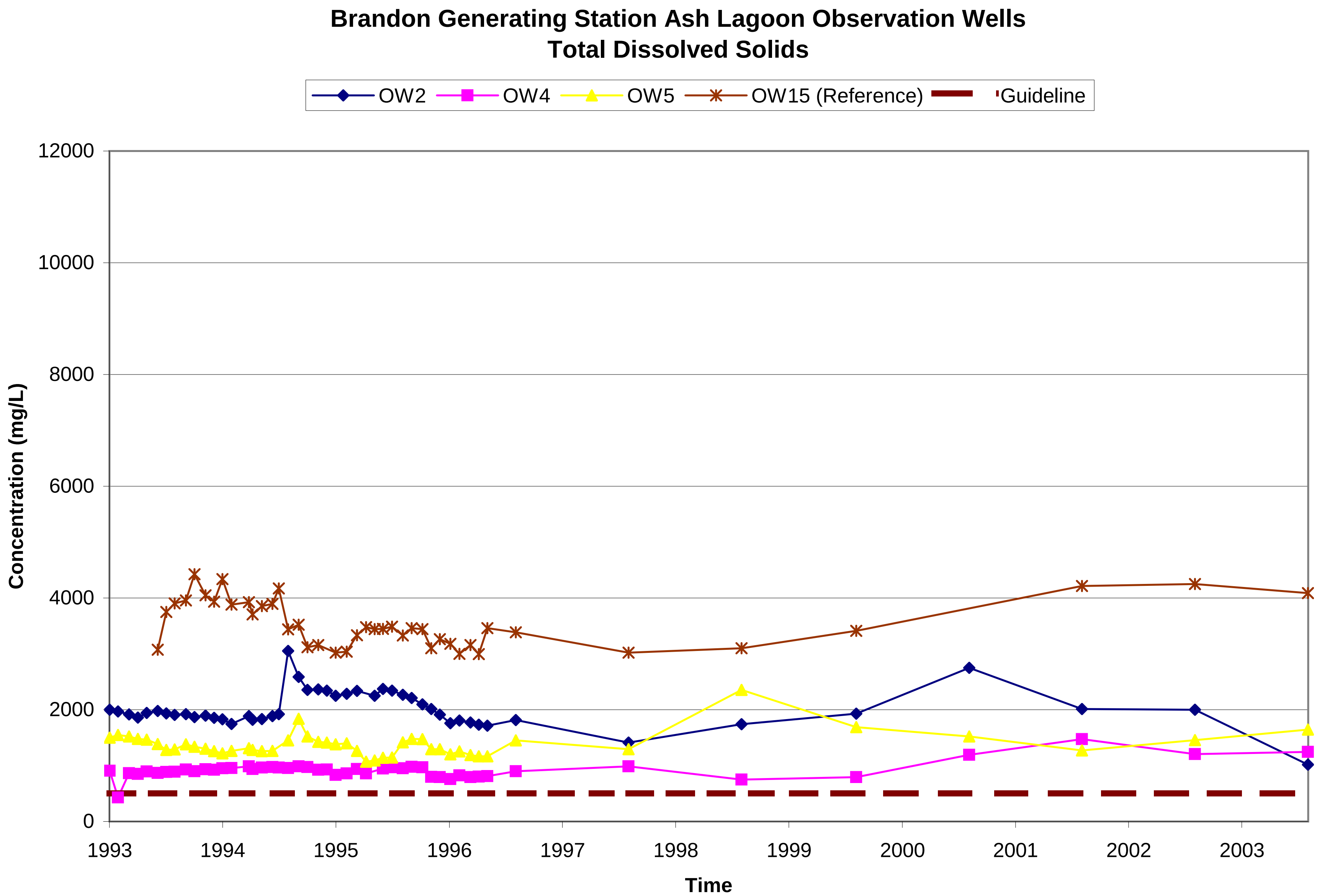

Brandon Generating Station Ash Lagoon Observation Wells
Total Dissolved Solids
OW2
OW4
OW5
OW15 (Reference)
Guideline
12000
10000
8000
6000
4000
2000
0
Concentration (mg/L)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 8

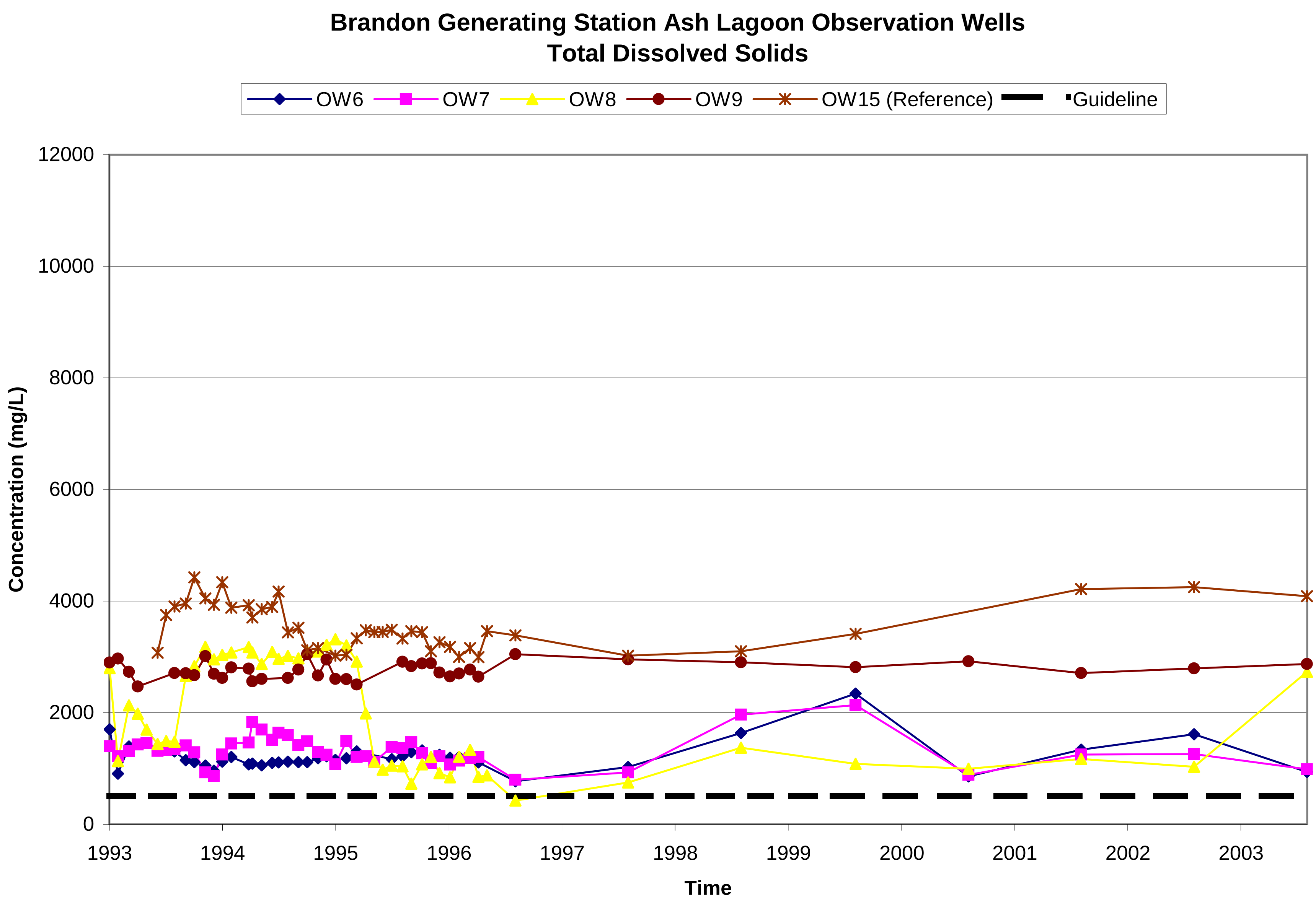

Brandon Generating Station Ash Lagoon Observation Wells
Total Dissolved Solids
OW6
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (mg/L)
12000
10000
8000
6000
4000
2000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 9

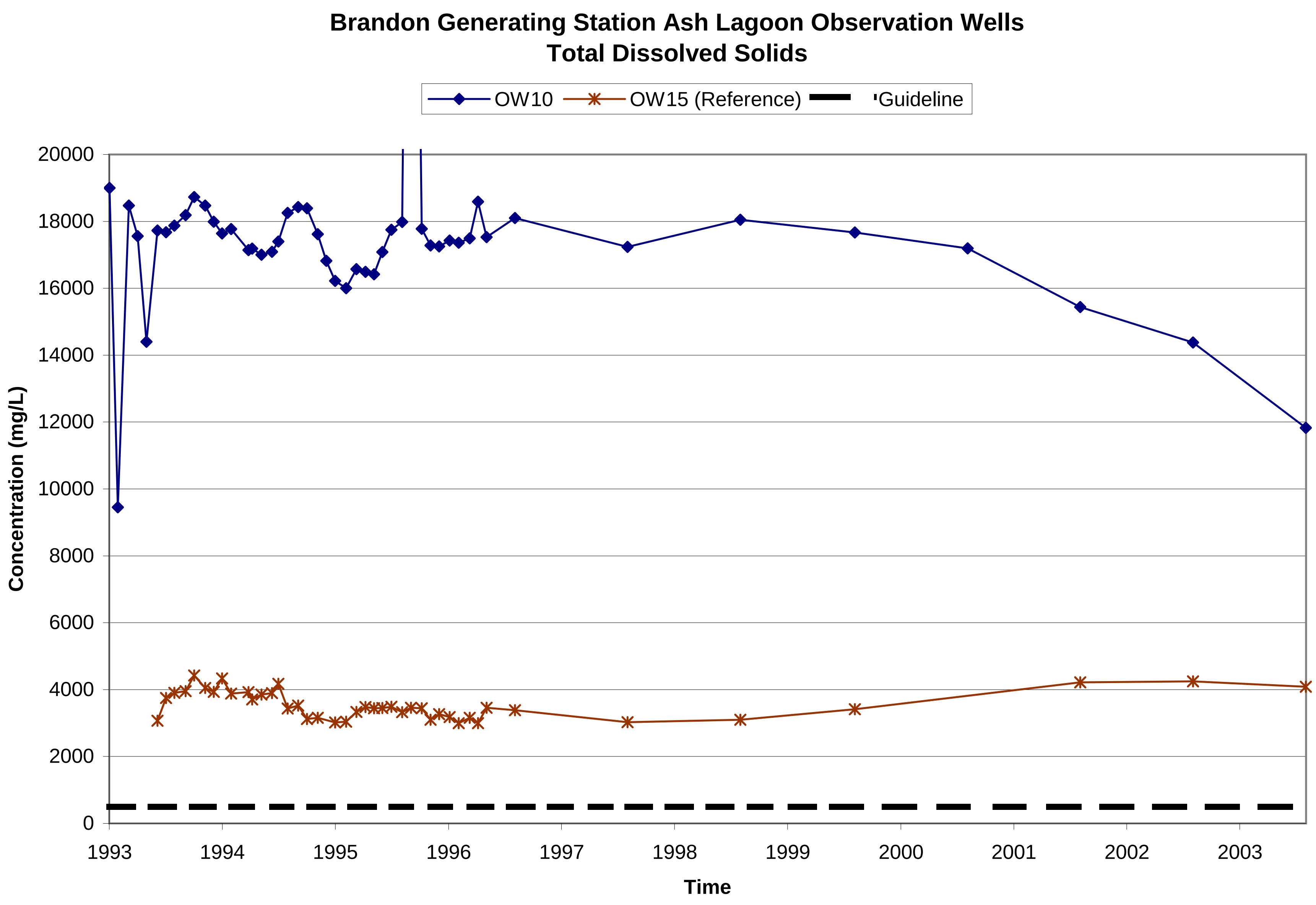

Brandon Generating Station Ash Lagoon Observation Wells
Total Dissolved Solids
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 10

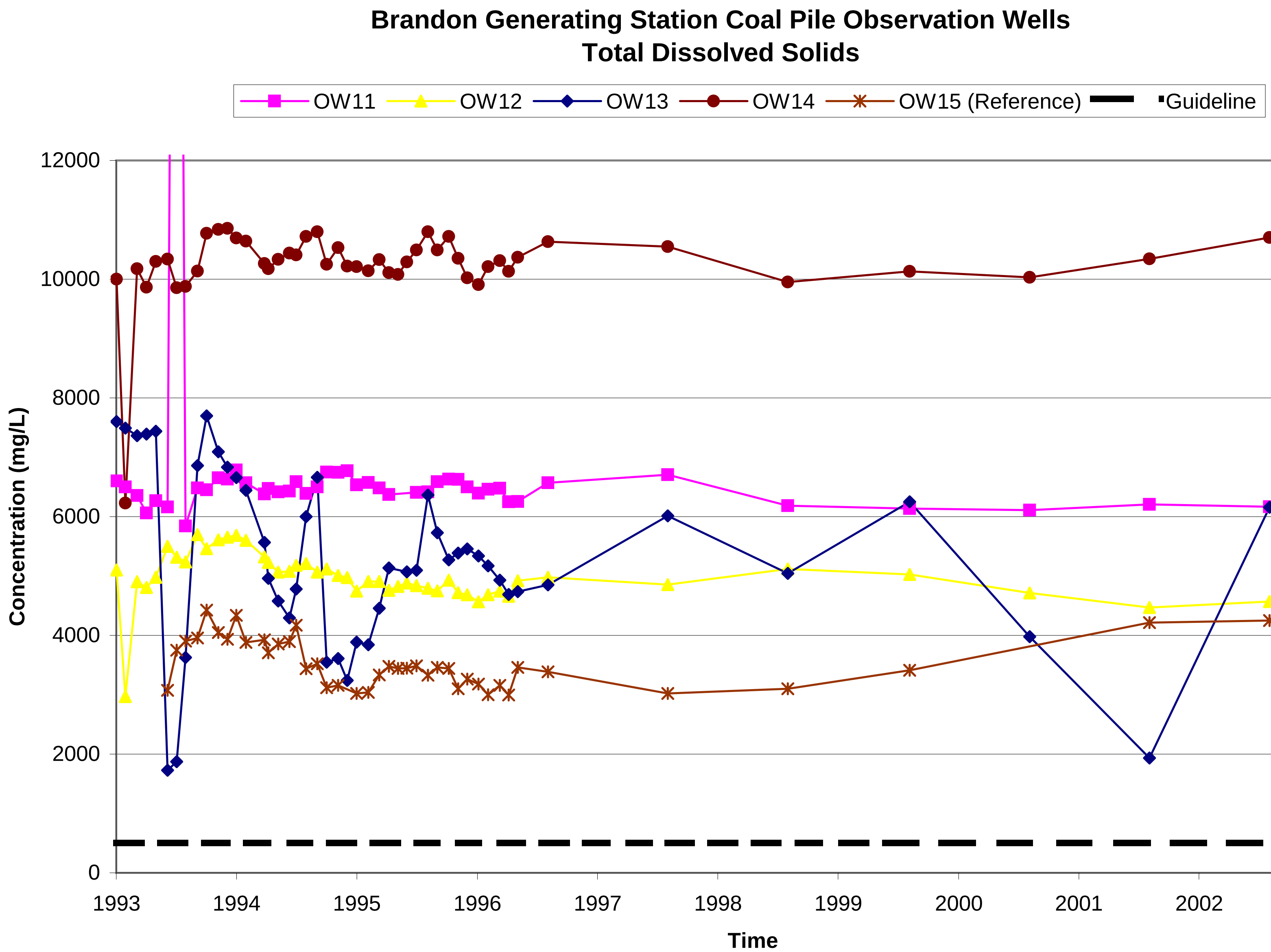

Brandon Generating Station Coal Pile Observation Wells
Total Dissolved Solids
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
12000
10000
8000
6000
4000
2000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 11

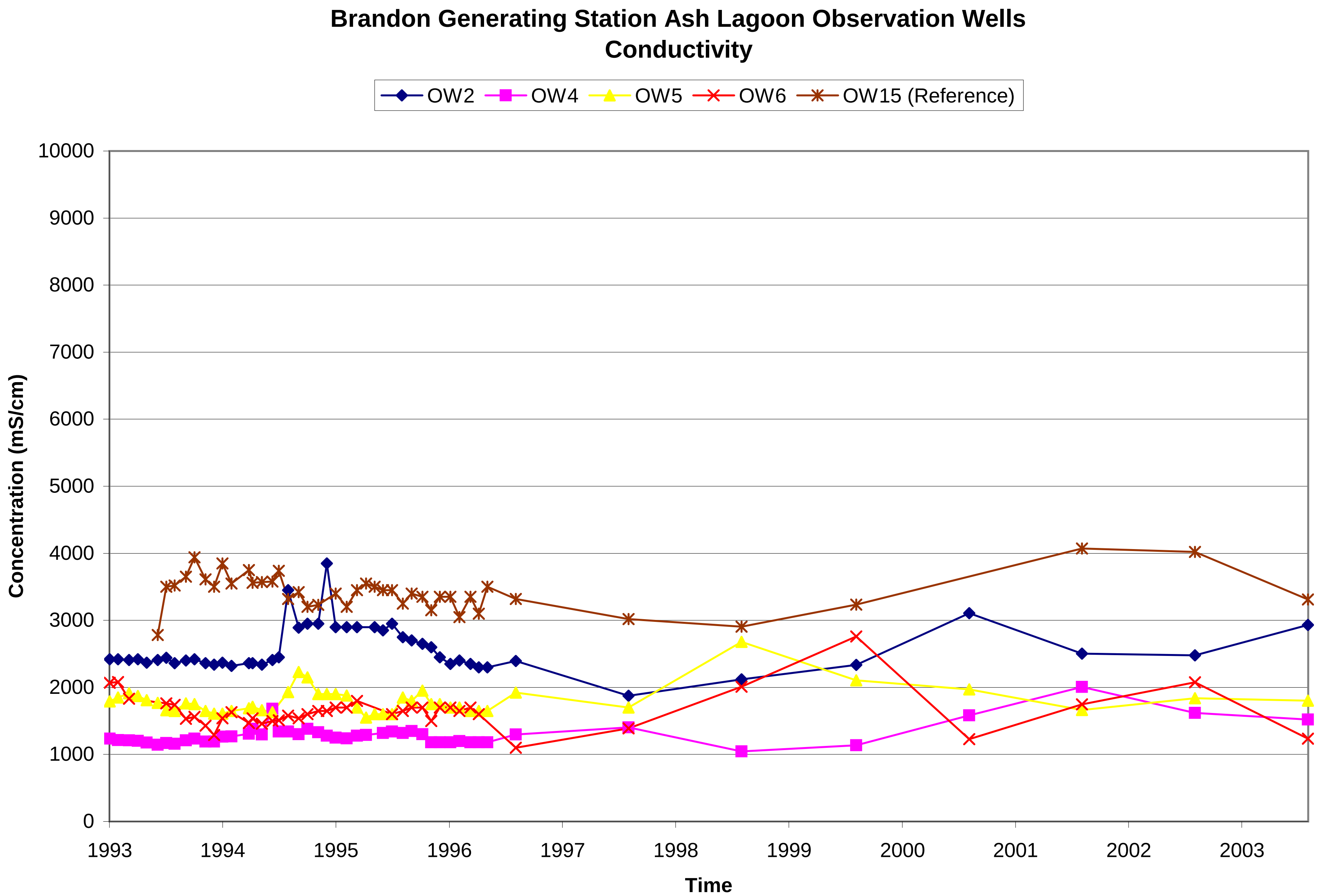

Brandon Generating Station Ash Lagoon Observation Wells
Conductivity
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mS/cm)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 12

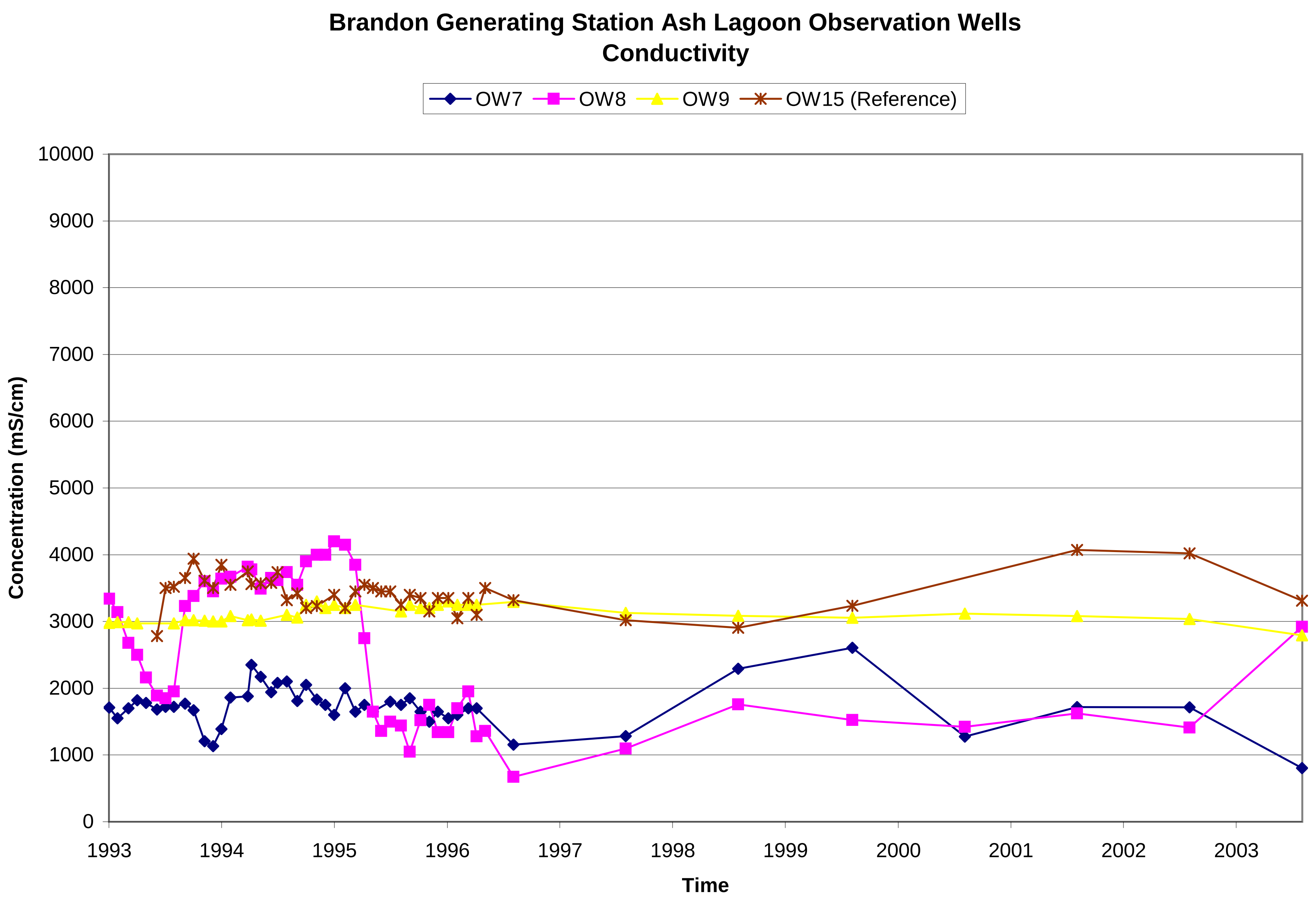
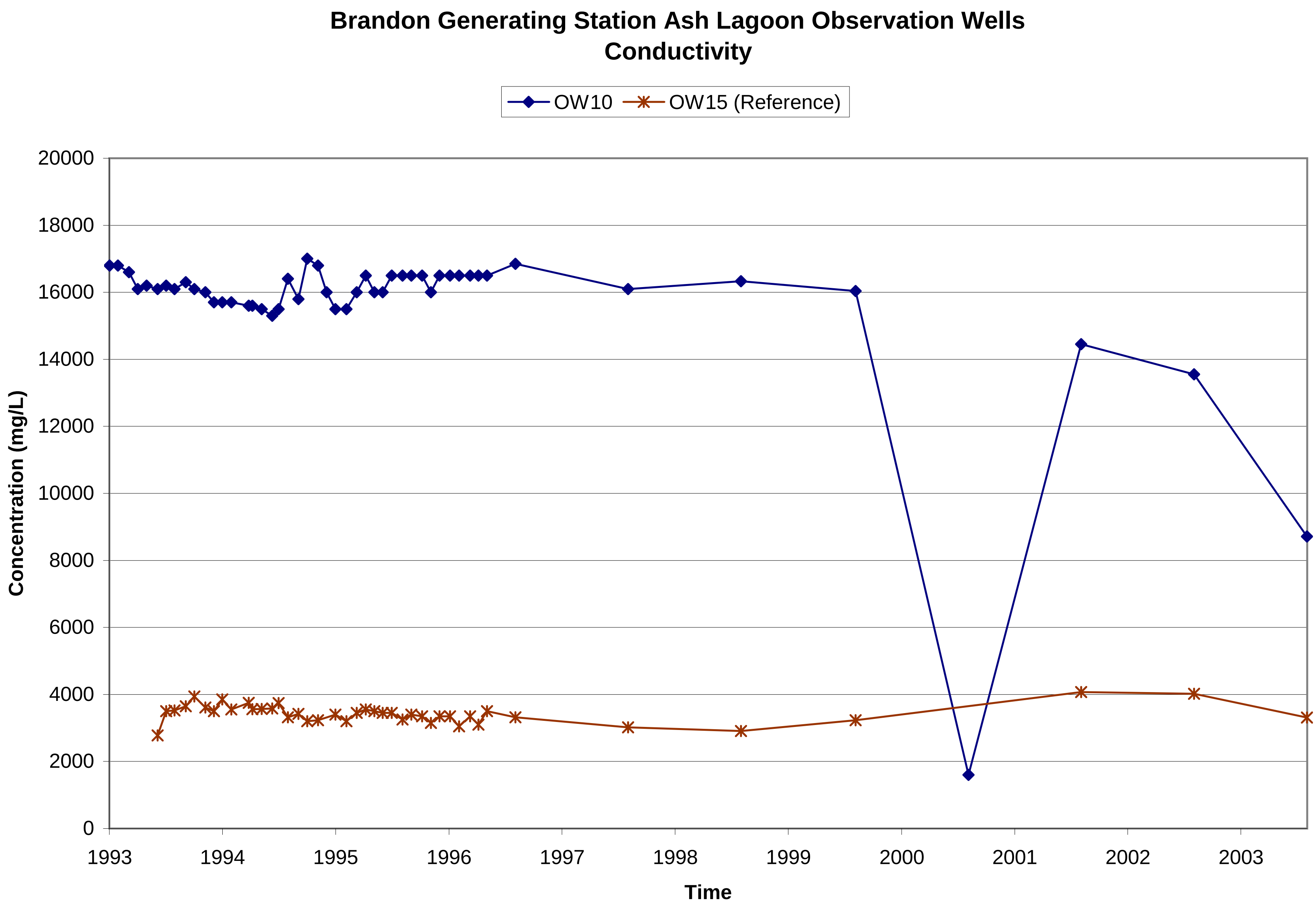

Brandon Generating Station Ash Lagoon Observation Wells
Conductivity
OW7
OW8
OW9
OW15 (Reference)
Concentration (mS/cm)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 13



Brandon Generating Station Ash Lagoon Observation Wells
Conductivity
OW10
OW15 (Reference)
Concentration (mg/L)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 14

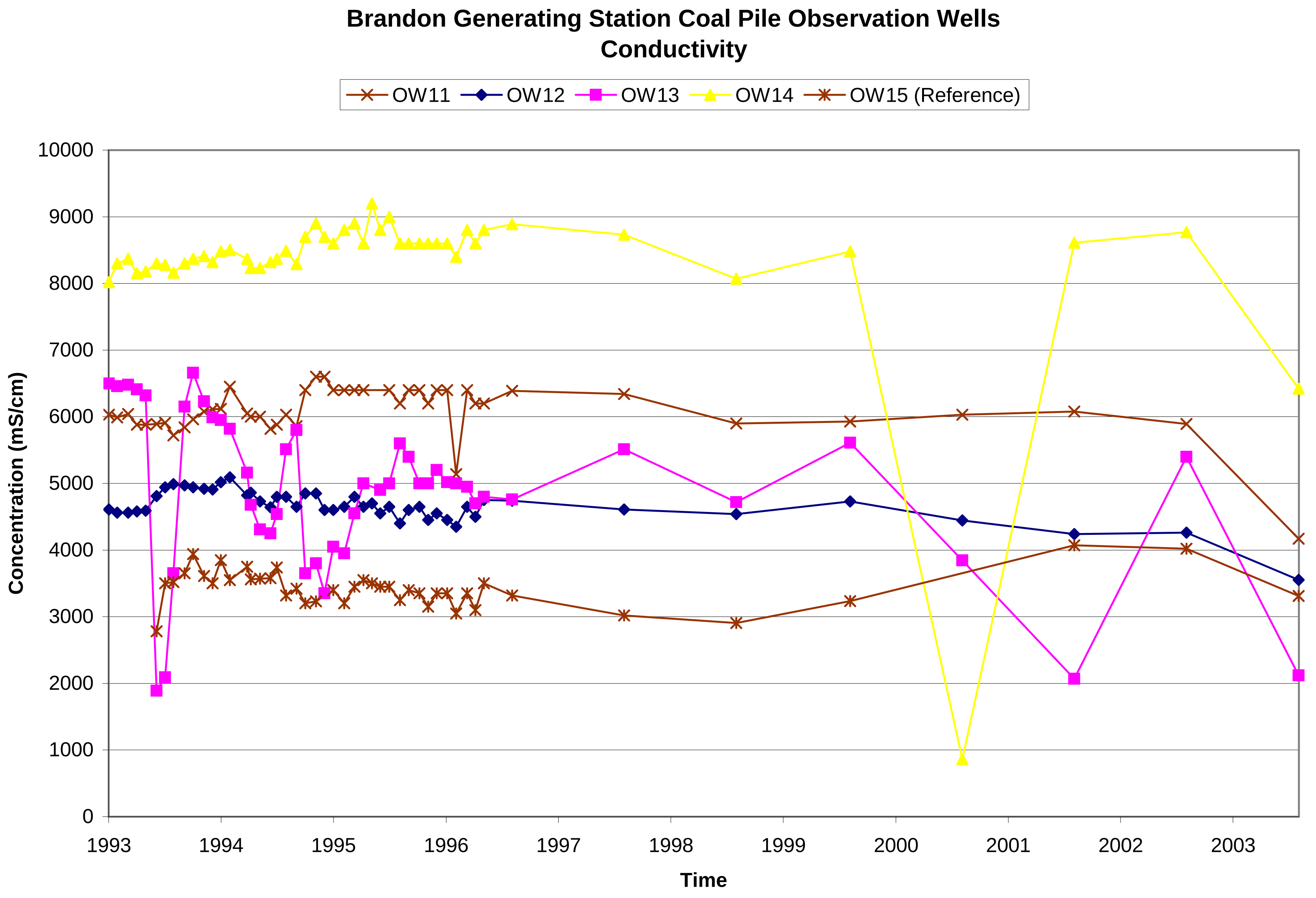
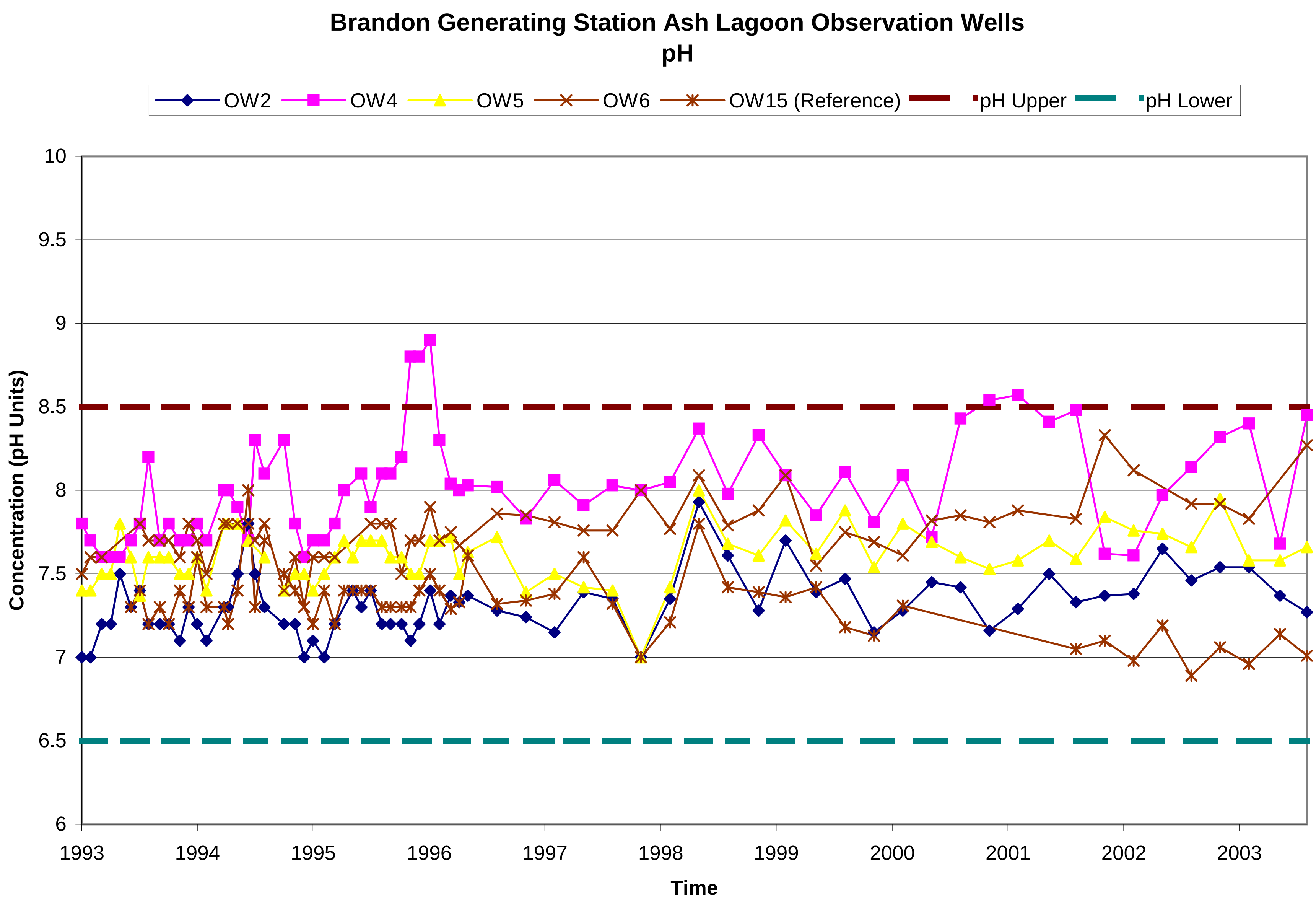

Brandon Generating Station Coal Pile Observation Wells
Conductivity
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mS/cm)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 15



Brandon Generating Station Ash Lagoon Observation Wells
pH
OW2
OW4
OW5
OW6
OW15 (Reference)
pH Upper
pH Lower
Concentration (pH Units)
10
9.5
9
8.5
8
7.5
7
6.5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 16

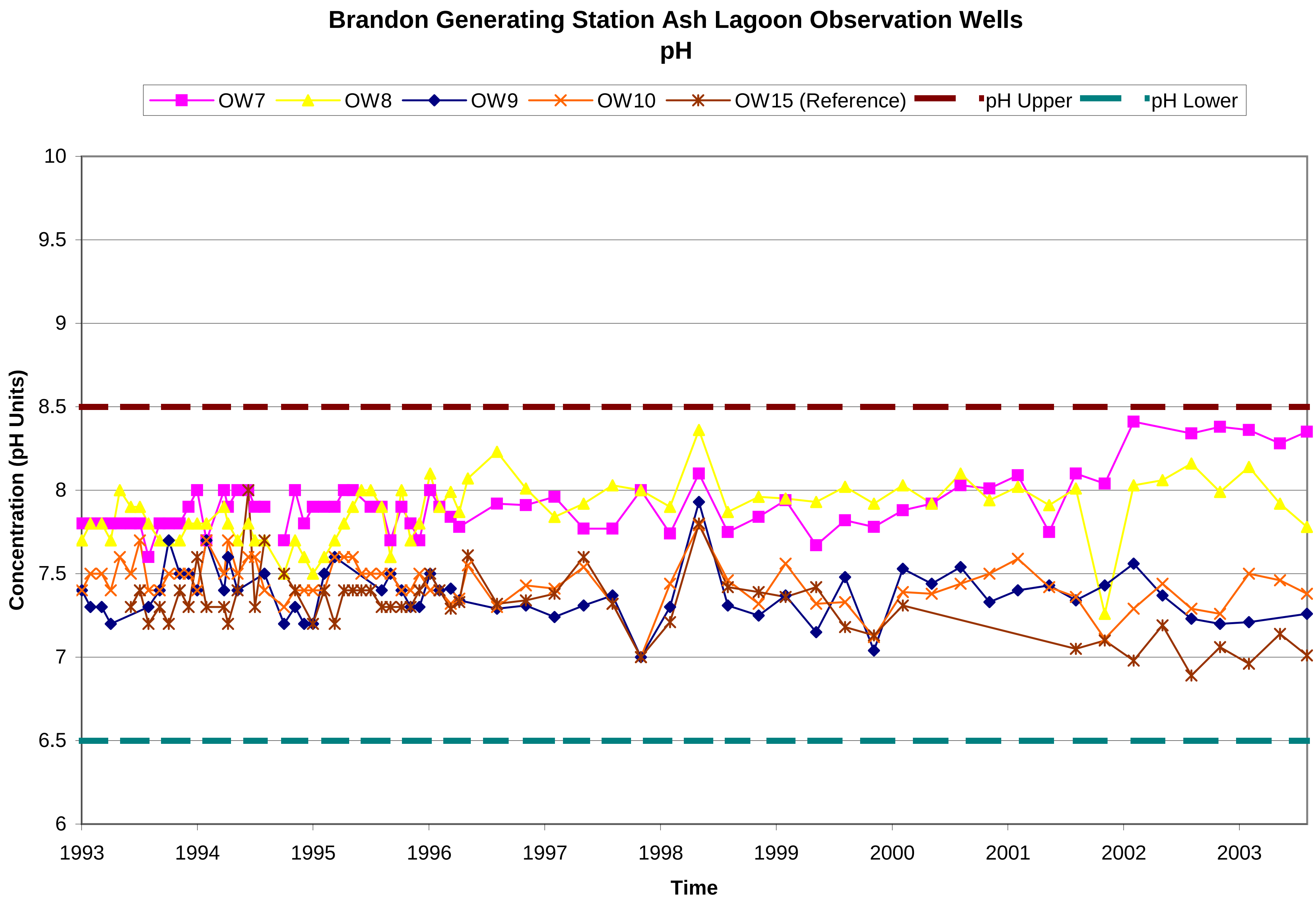

Brandon Generating Station Ash Lagoon Observation Wells
pH
OW7
OW8
OW9
OW10
OW15 (Reference)
pH Upper
pH Lower
Concentration (pH Units)
10
9.5
9
8.5
8
7.5
7
6.5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 17

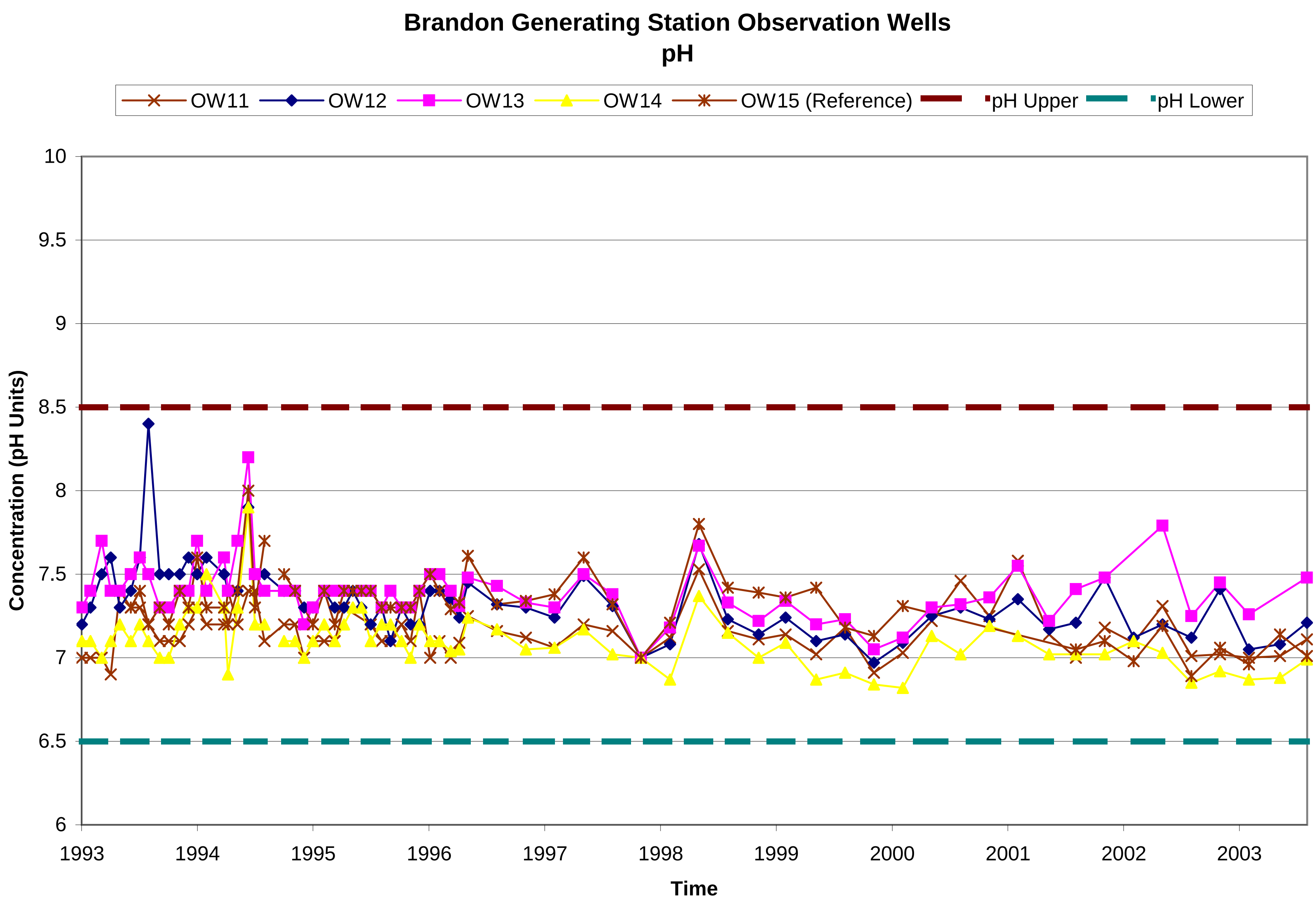
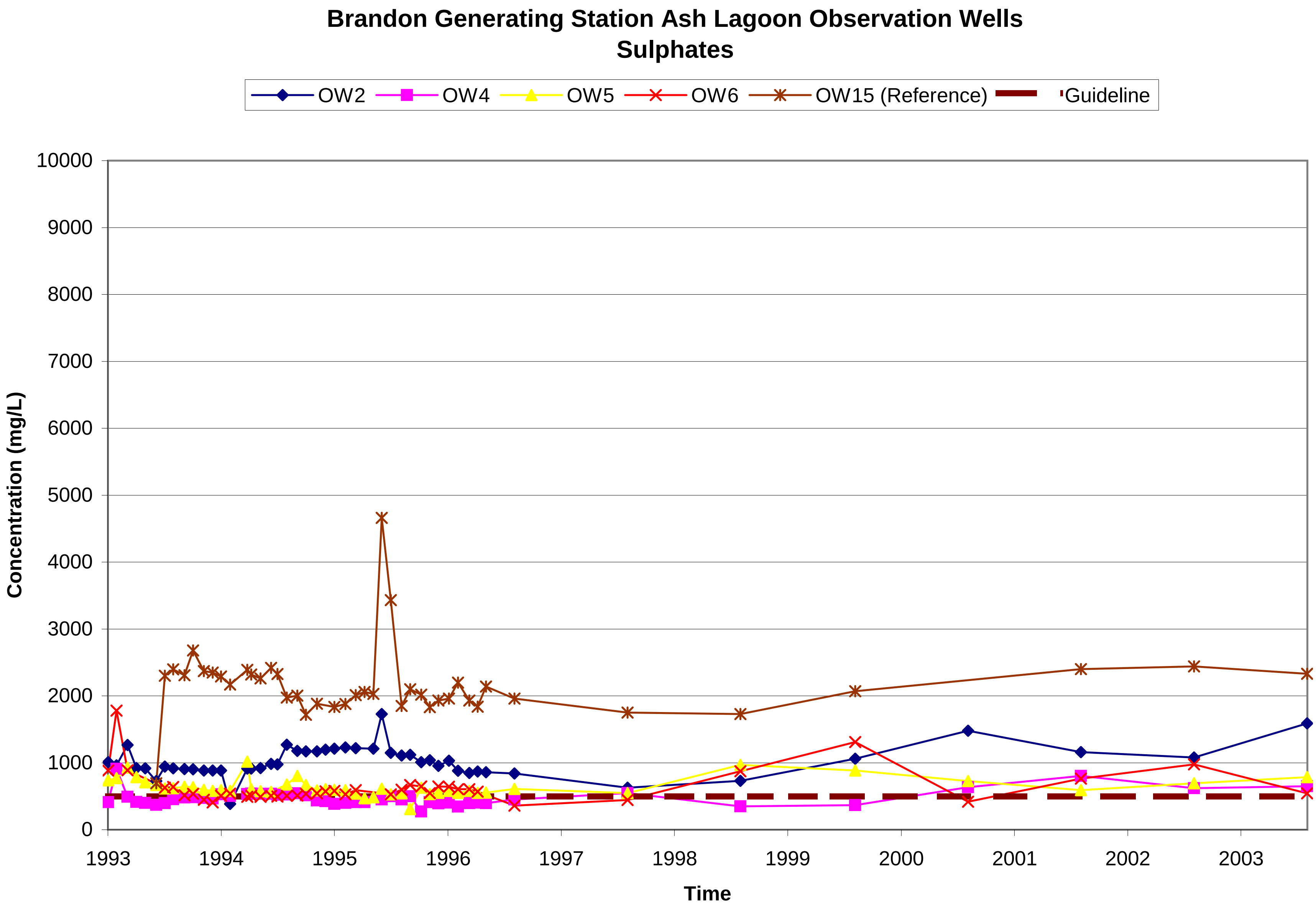
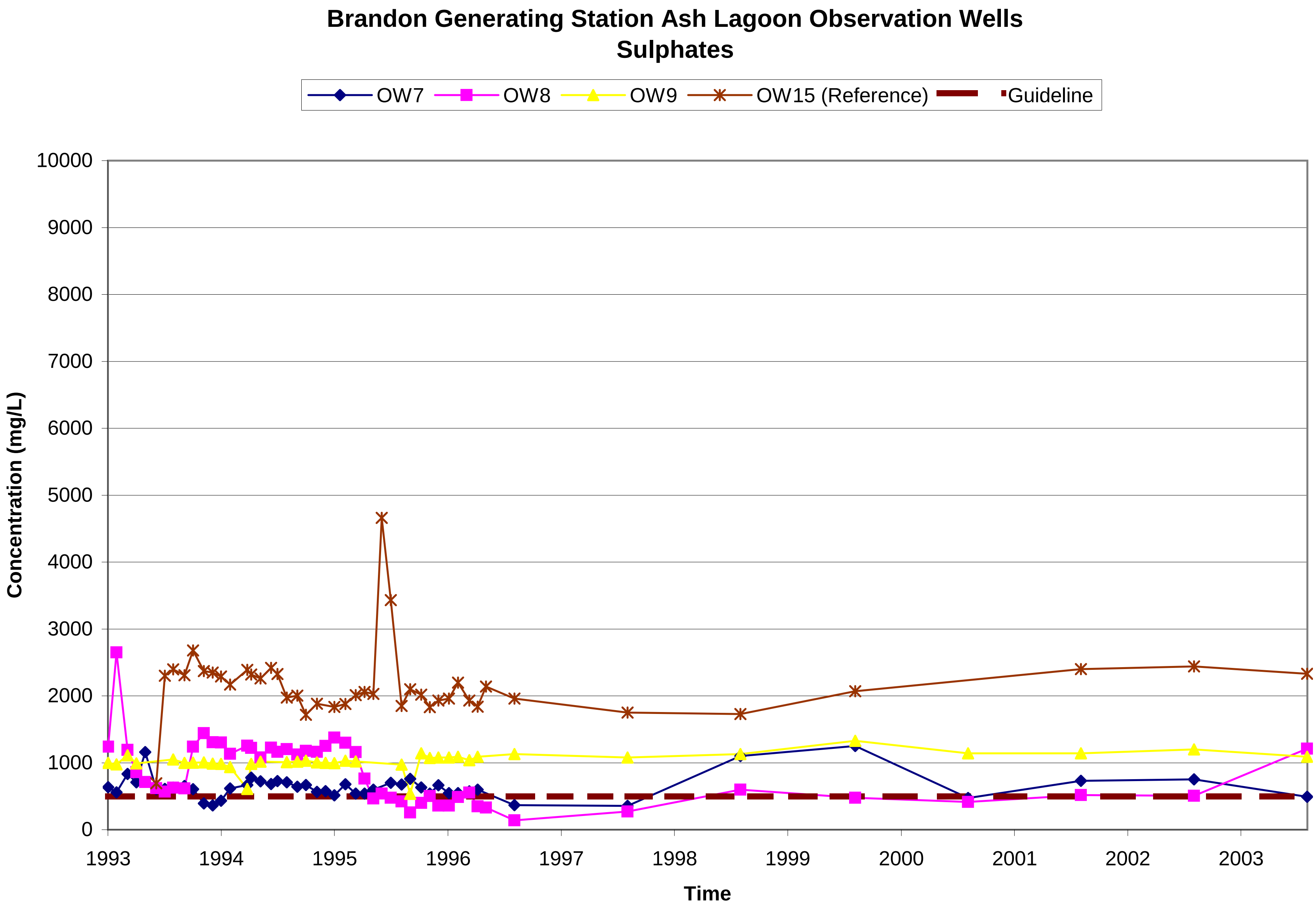

Brandon Generating Station Observation Wells
pH
OW11
OW12
OW13
OW14
OW15 (Reference)
pH Upper
pH Lower
Concentration (pH Units)
10
9.5
9
8.5
8
7.5
7
6.5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 18



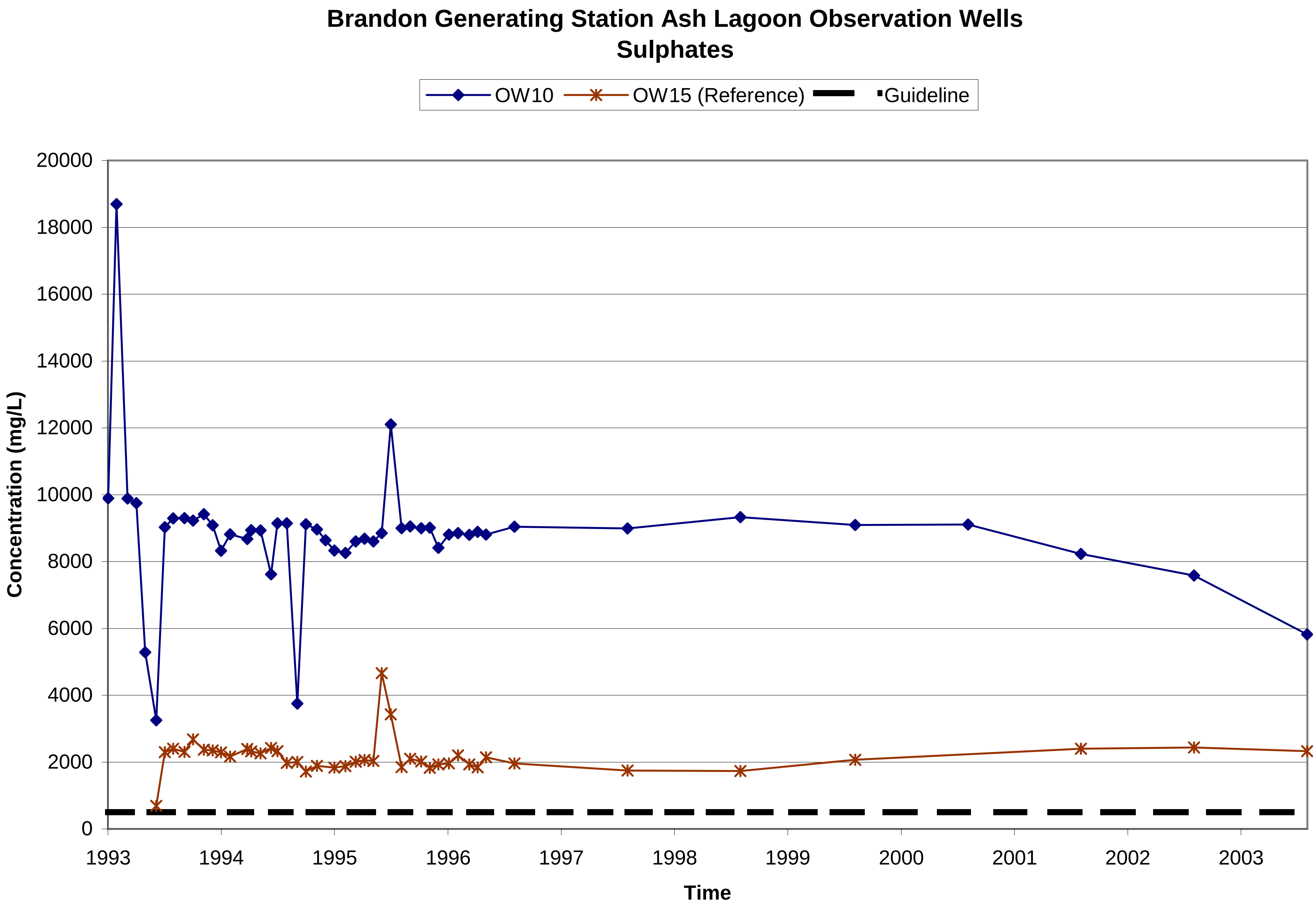
Brandon Generating Station Ash Lagoon Observation Wells
Sulphates
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 19



Brandon Generating Station Ash Lagoon Observation Wells
Sulphates
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (mg/L)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 20



Brandon Generating Station Ash Lagoon Observation Wells
Sulphates
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 21

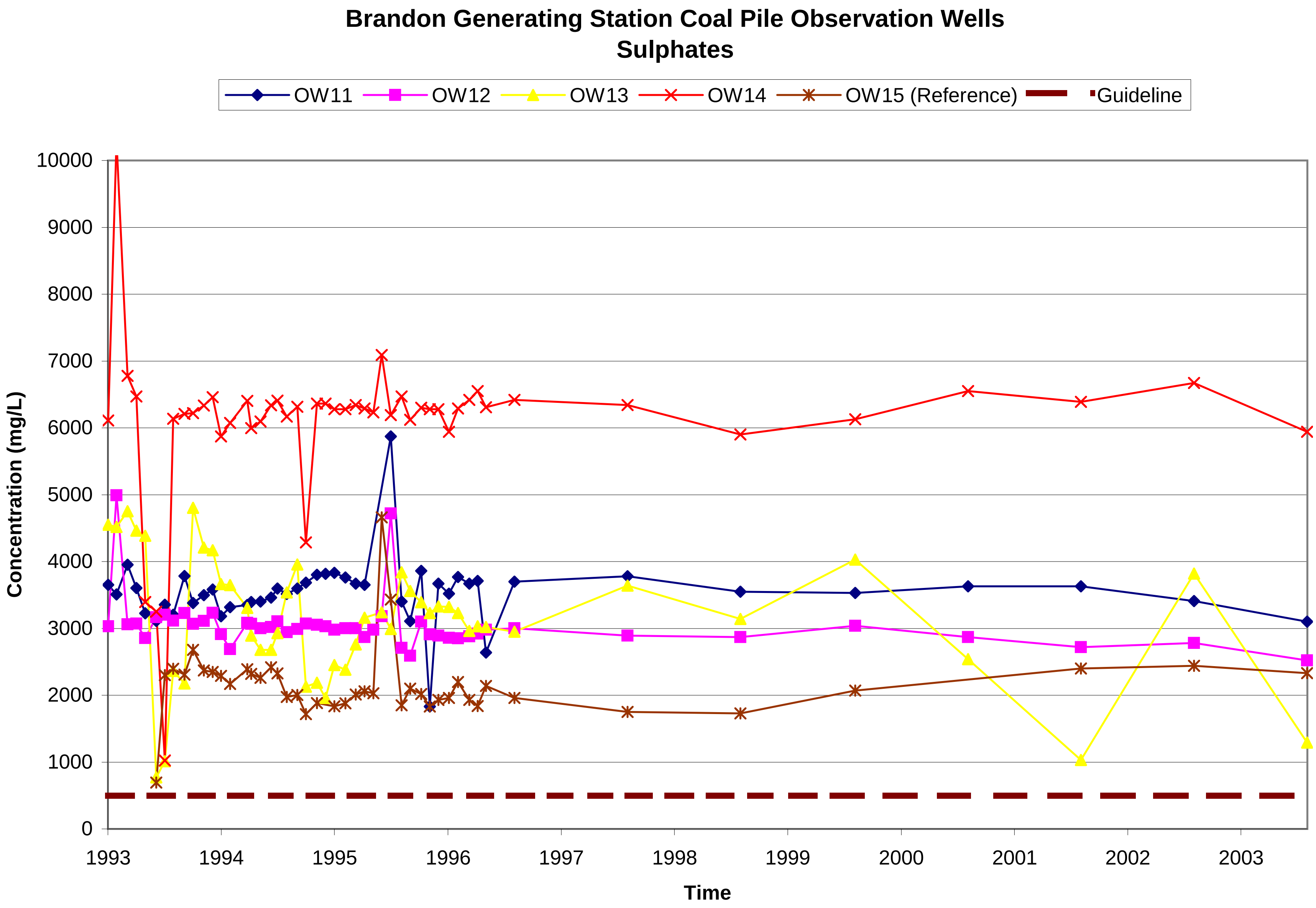

Brandon Generating Station Coal Pile Observation Wells
Sulphates
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 22

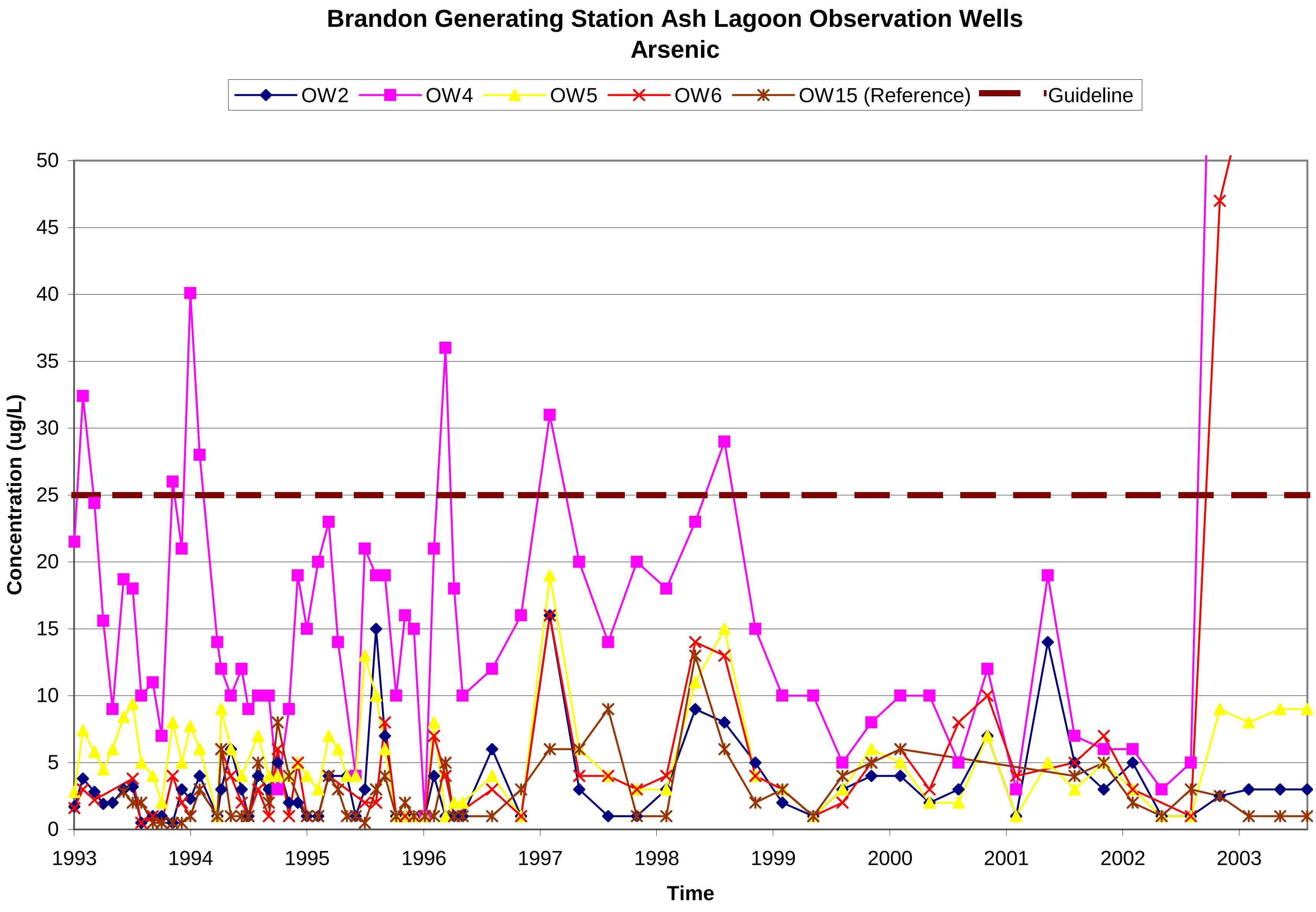
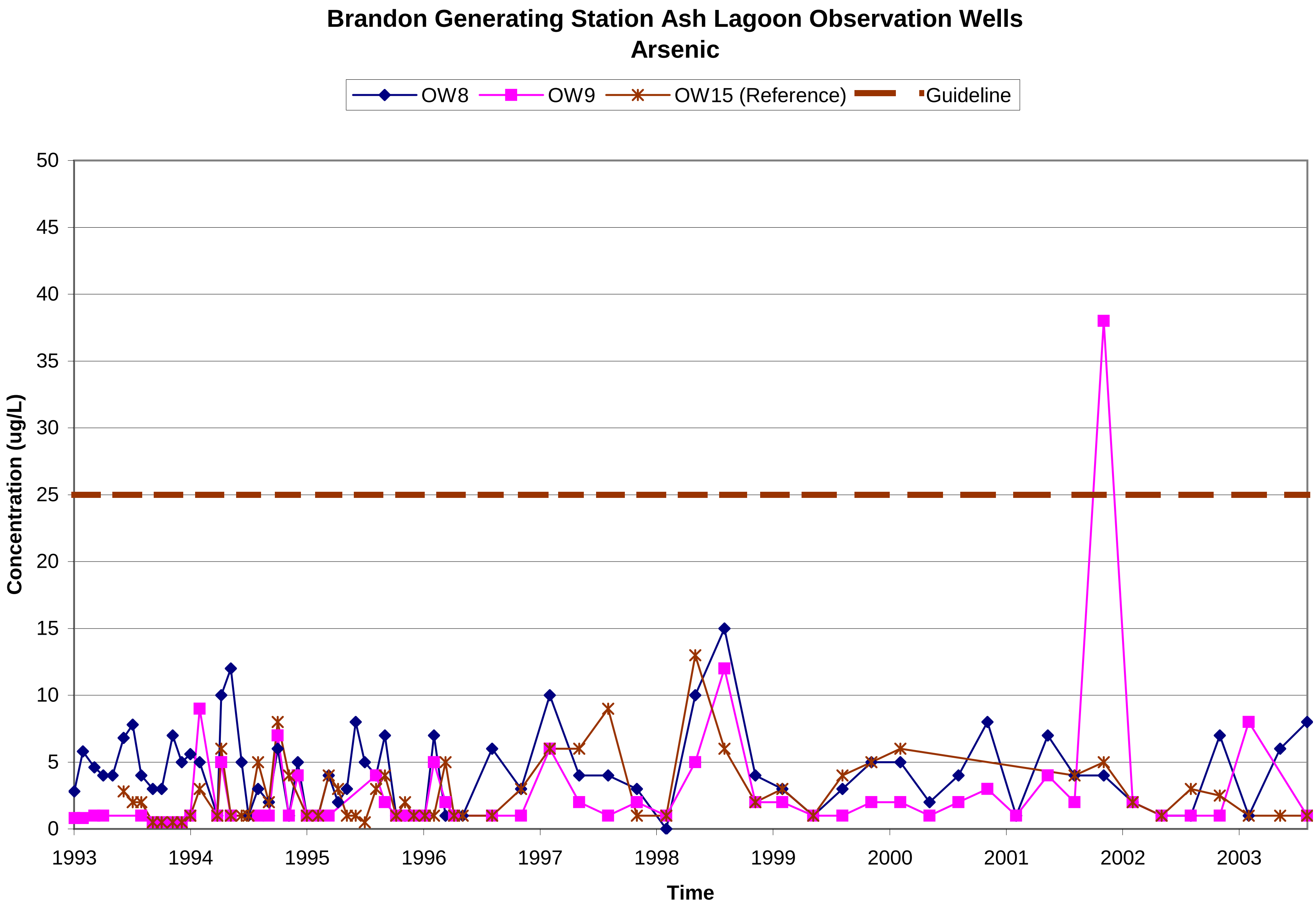

Brandon Generating Station Ash Lagoon Observation Wells
Arsenic
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
0
5
10
15
20
25
30
35
40
45
50
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 23



Brandon Generating Station Ash Lagoon Observation Wells
Arsenic
OW8
OW9
OW15 (Reference)
Guideline
Concentration (ug/L)
0
5
10
15
20
25
30
35
40
45
50
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 24

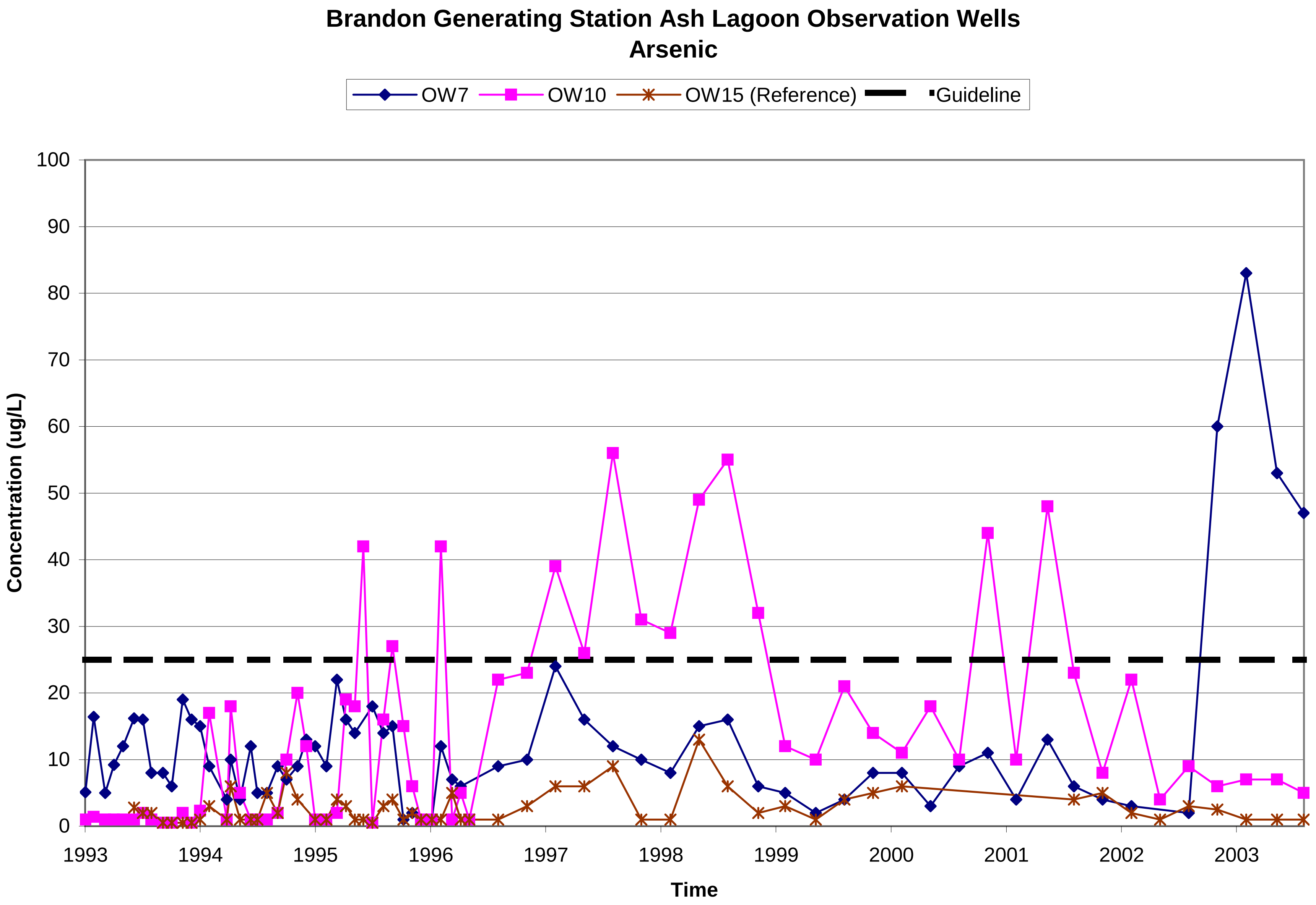

Brandon Generating Station Ash Lagoon Observation Wells
Arsenic
OW7
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
0
10
20
30
40
50
60
70
80
90
100
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 25

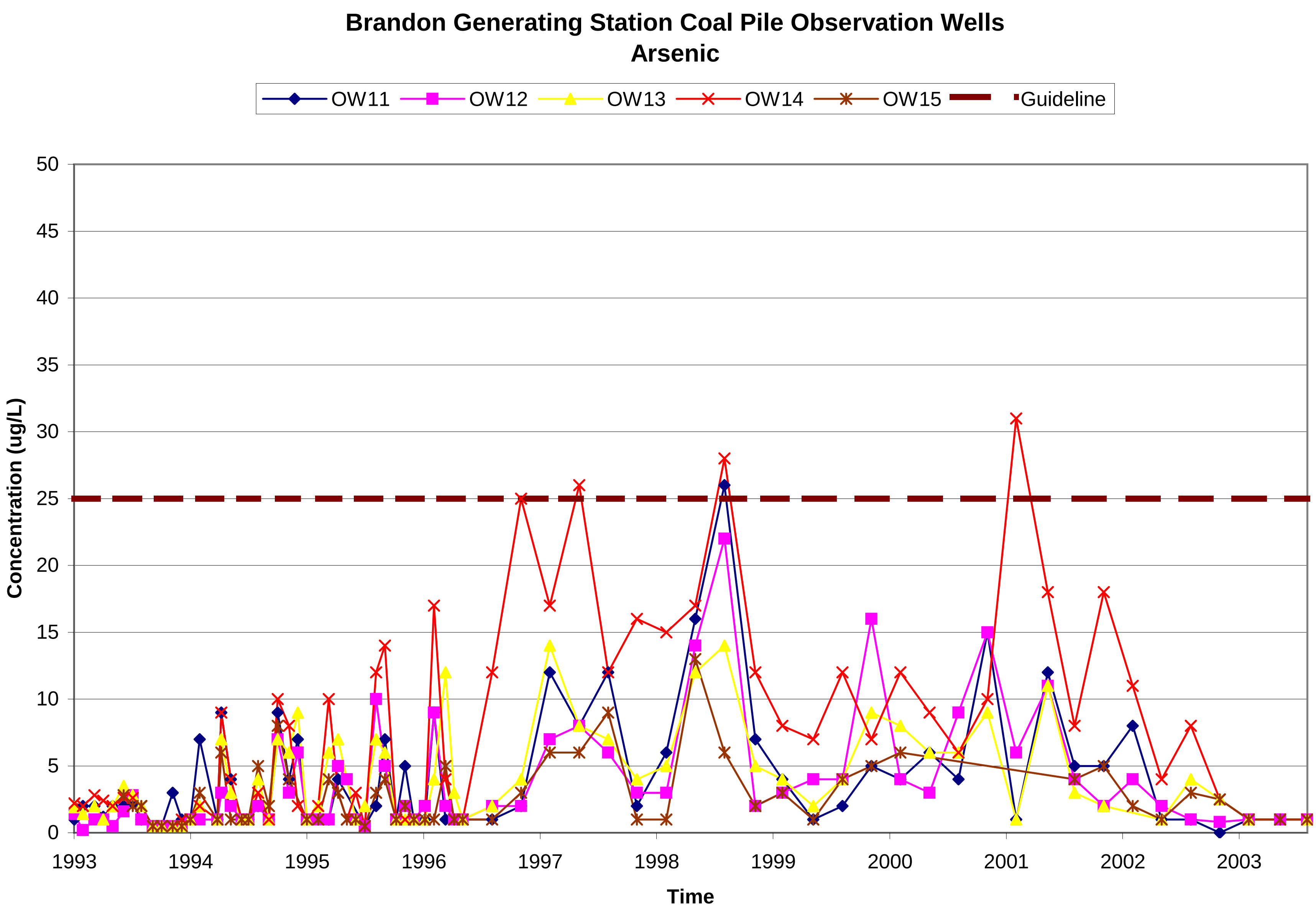
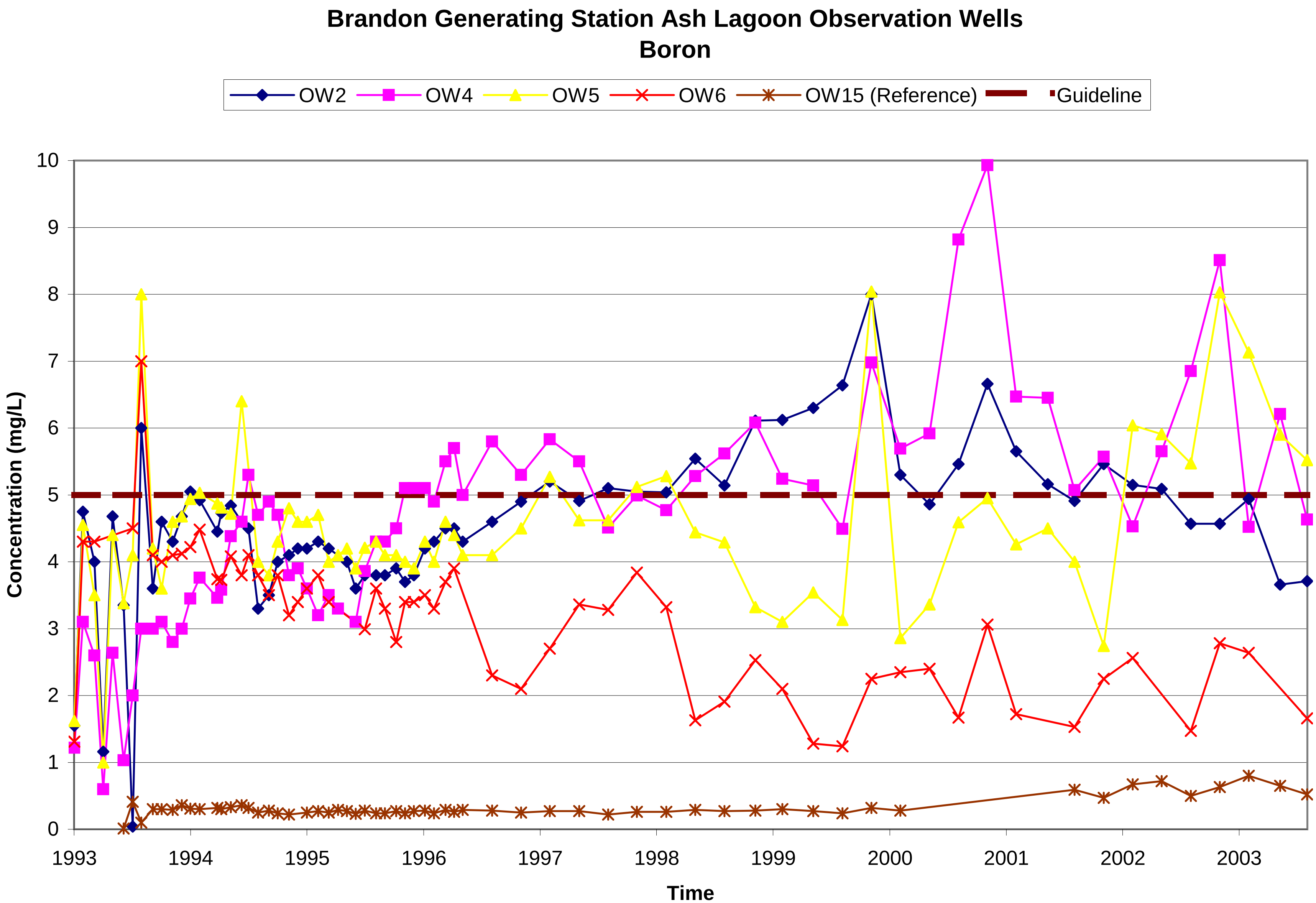

Brandon Generating Station Coal Pile Observation Wells
Arsenic
OW11
OW12
OW13
OW14
OW15
Guideline
Concentration (ug/L)
50
45
40
35
30
25
20
15
10
5
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 26



Brandon Generating Station Ash Lagoon Observation Wells
Boron
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 27

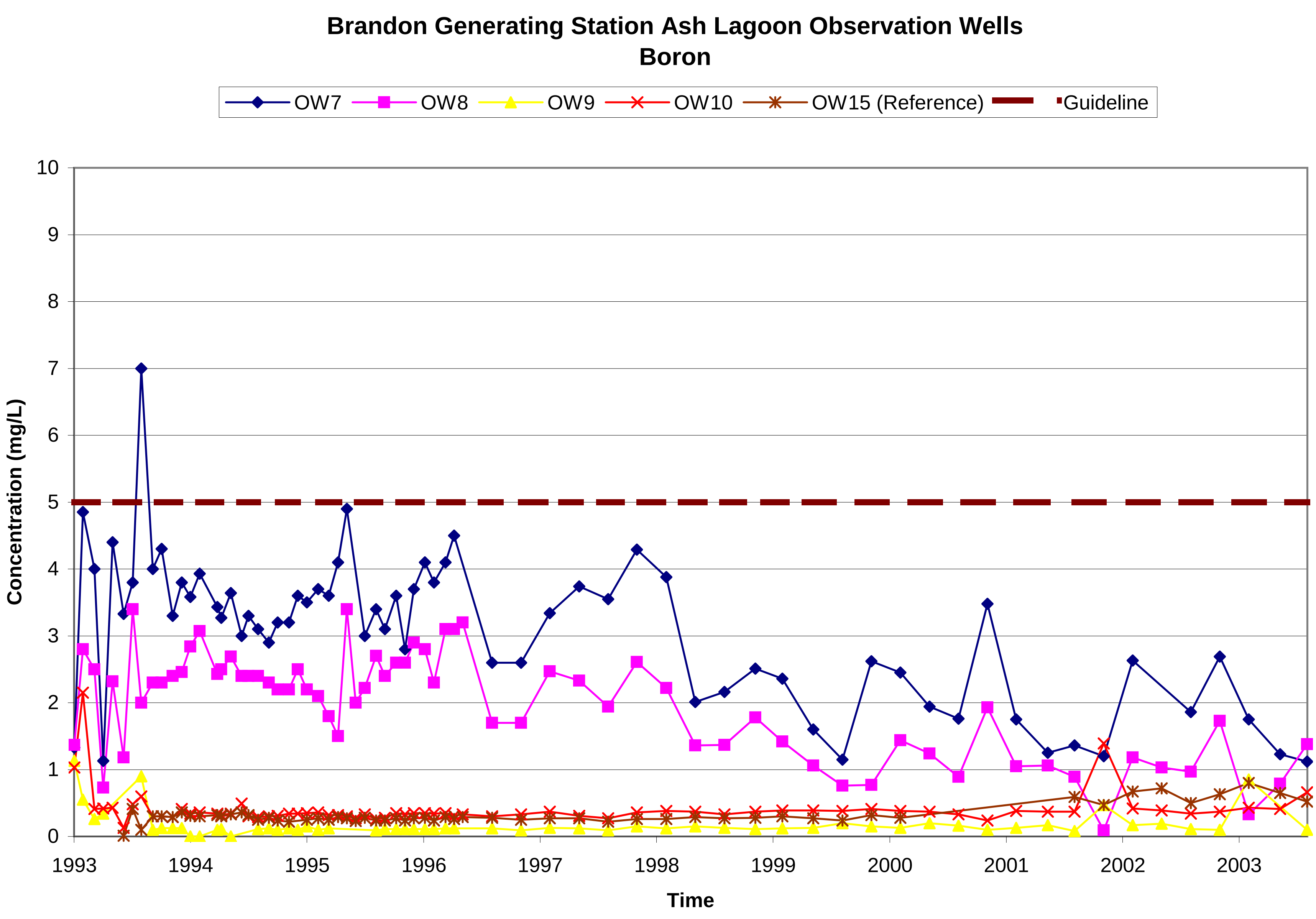

Brandon Generating Station Ash Lagoon Observation Wells
Boron
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
10
9
8
7
6
5
4
3
2
1
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 28

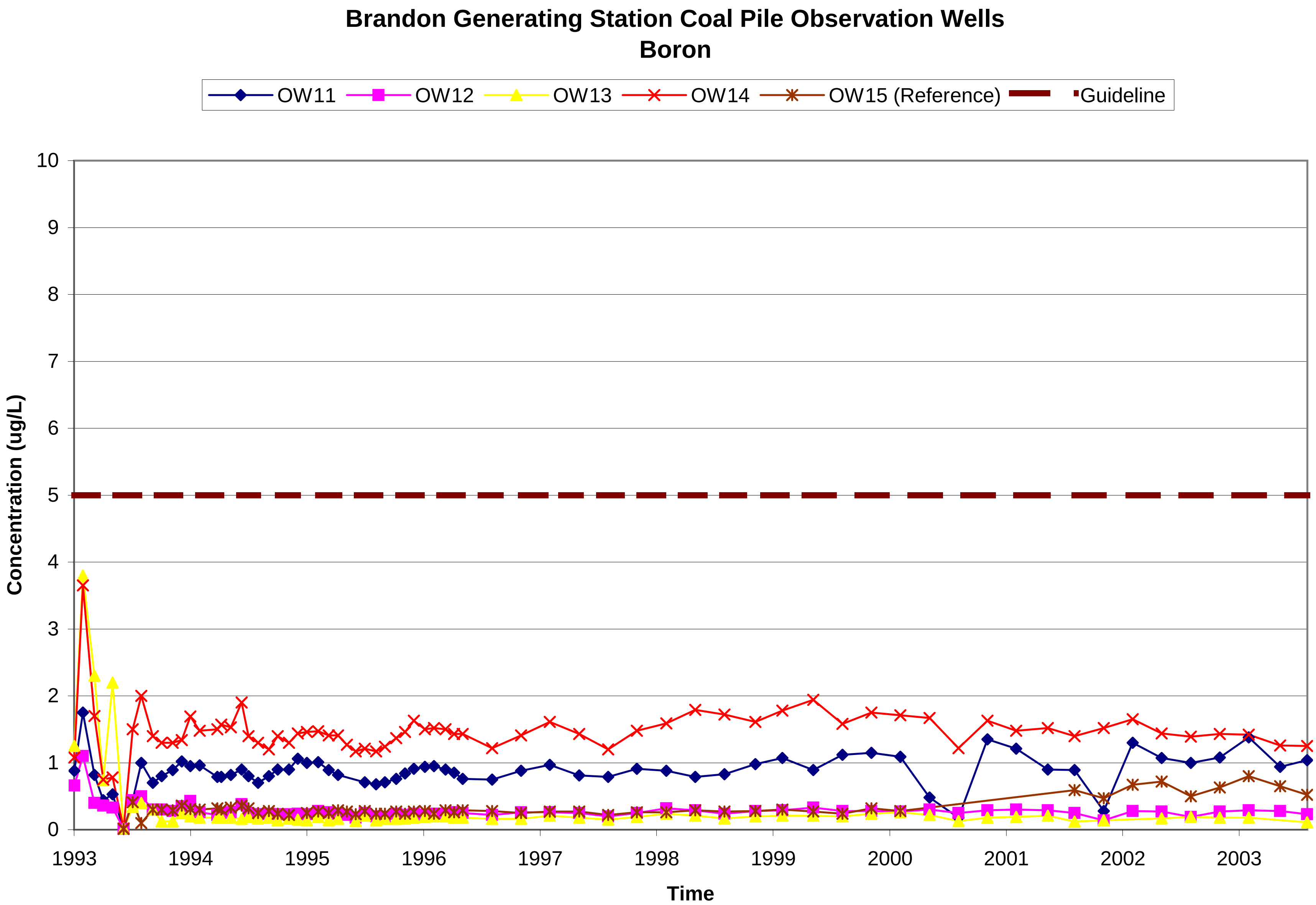

Brandon Generating Station Coal Pile Observation Wells
Boron
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
10
9
8
7
6
5
4
3
2
1
0
Concentration (ug/L)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 29

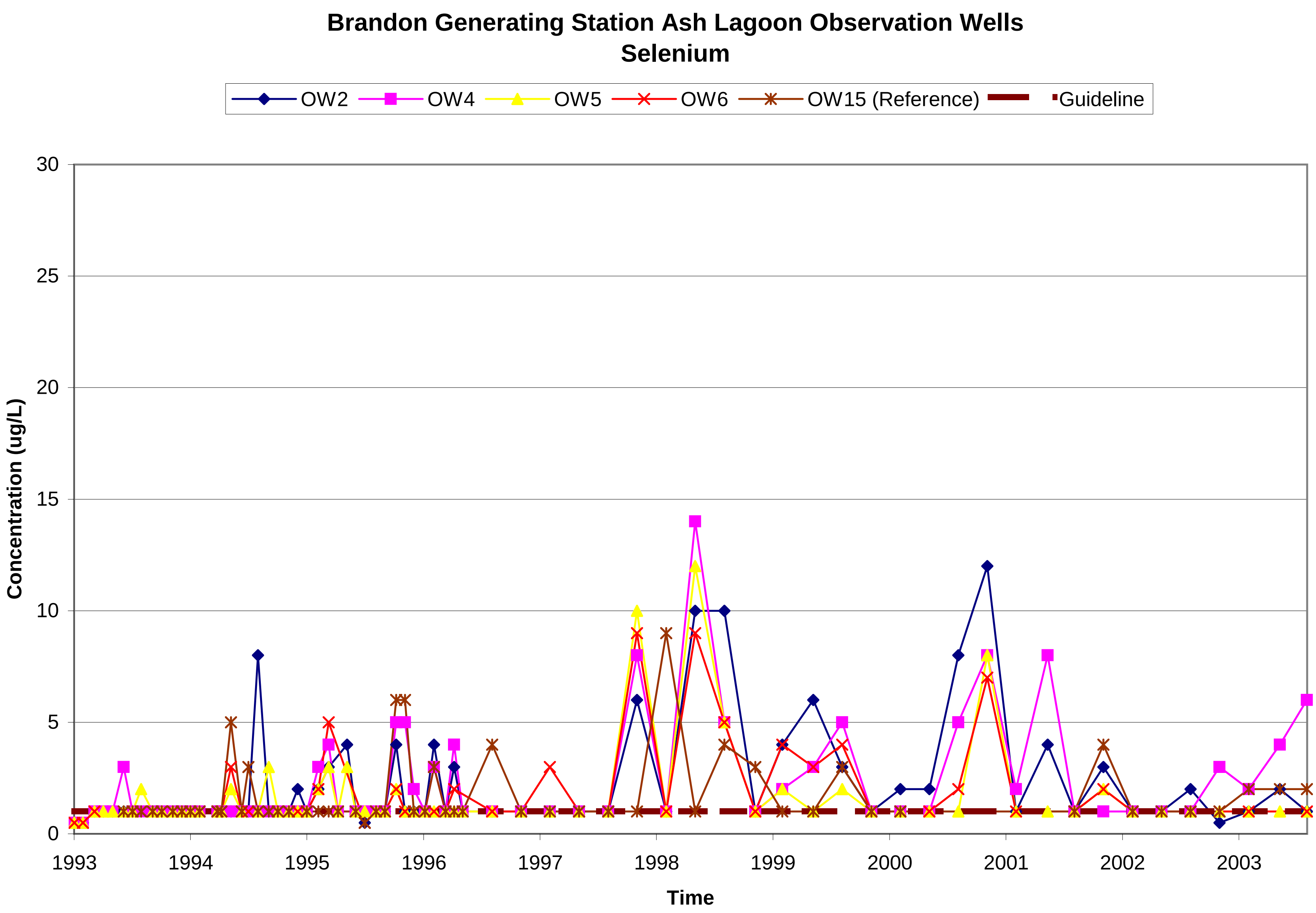

Brandon Generating Station Ash Lagoon Observation Wells
Selenium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
30
25
20
15
10
5
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 30

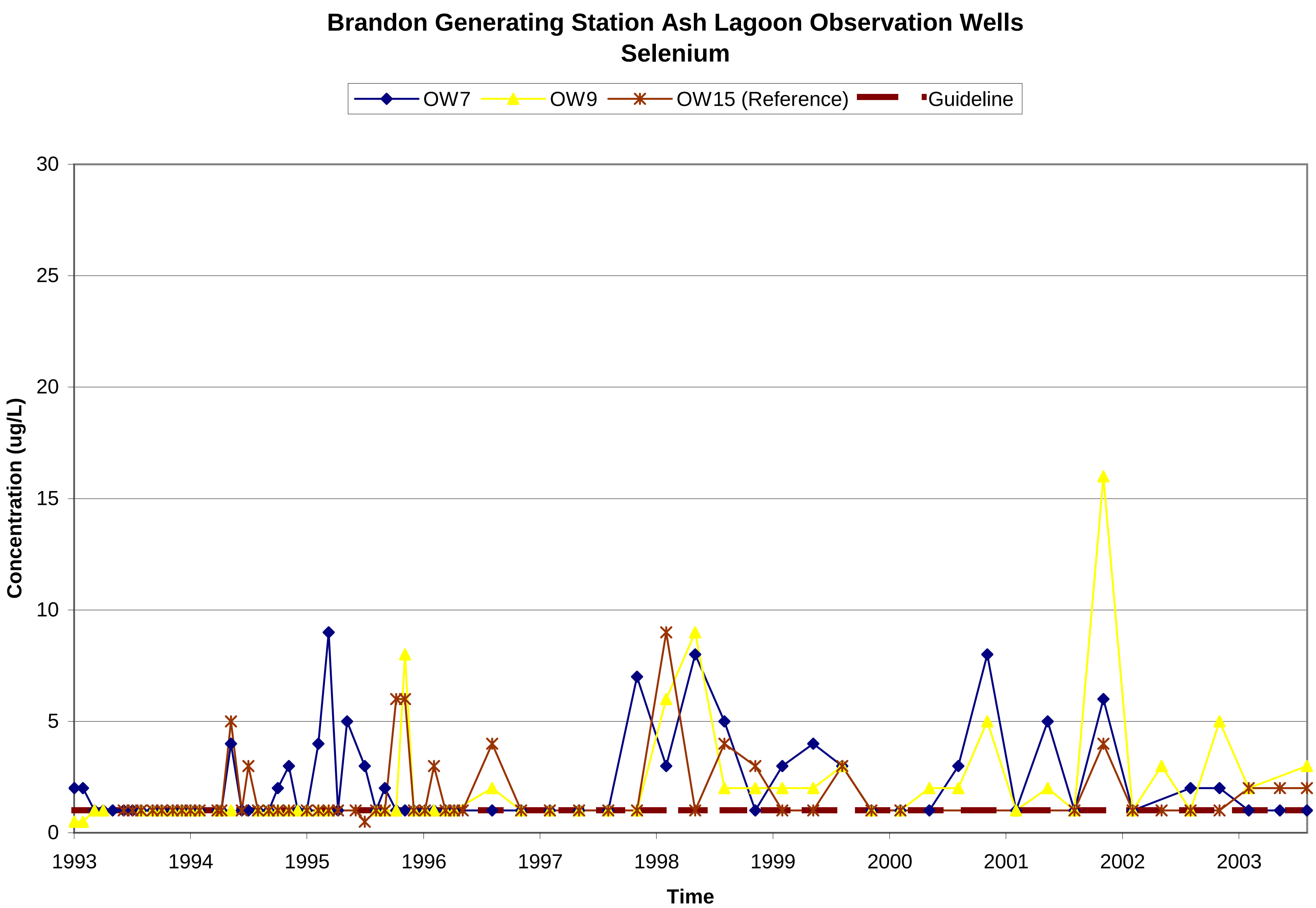

Brandon Generating Station Ash Lagoon Observation Wells
Selenium
OW7
OW9
OW15 (Reference)
Guideline
Concentration (ug/L)
0
5
10
15
20
25
30
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 31

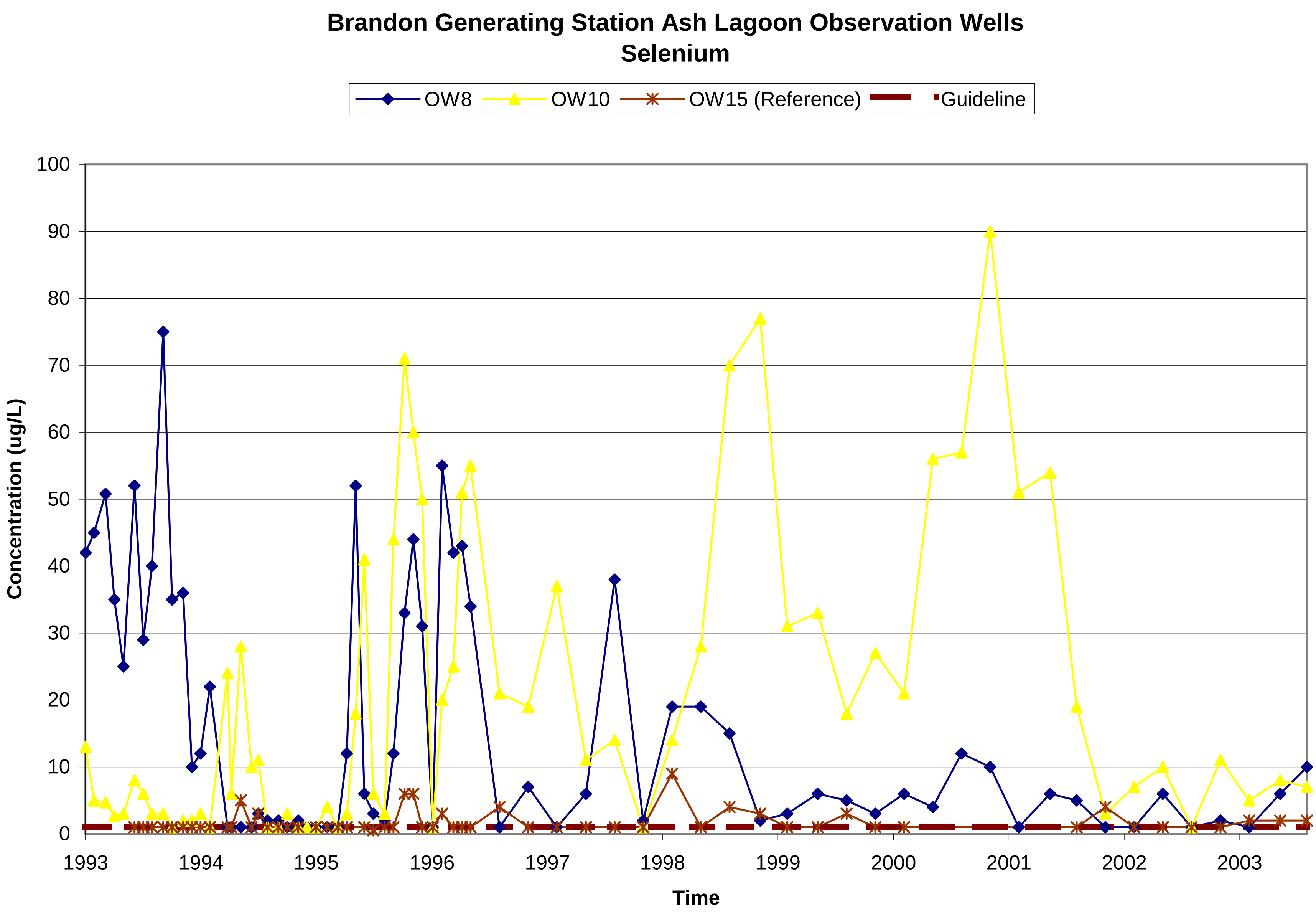
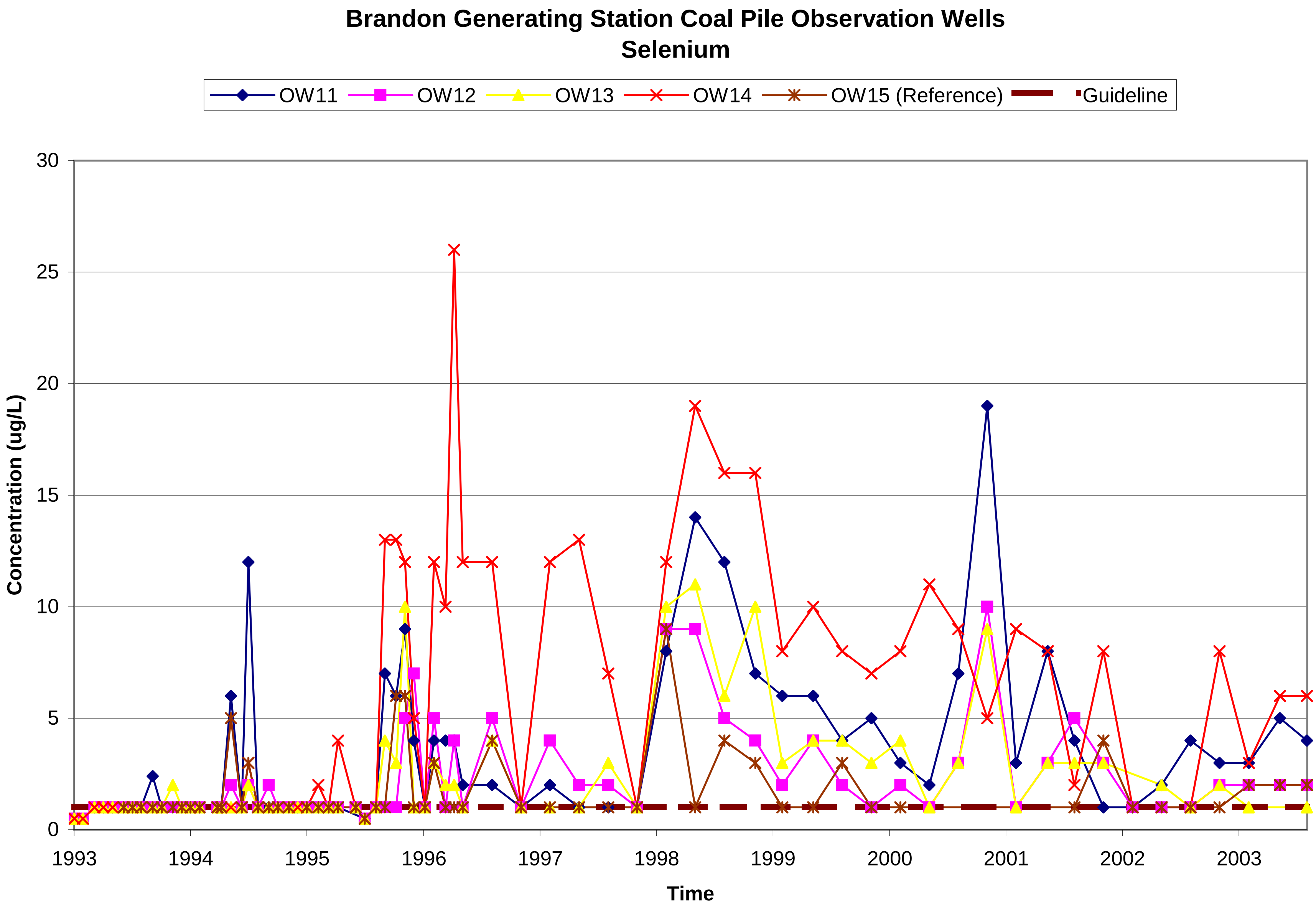
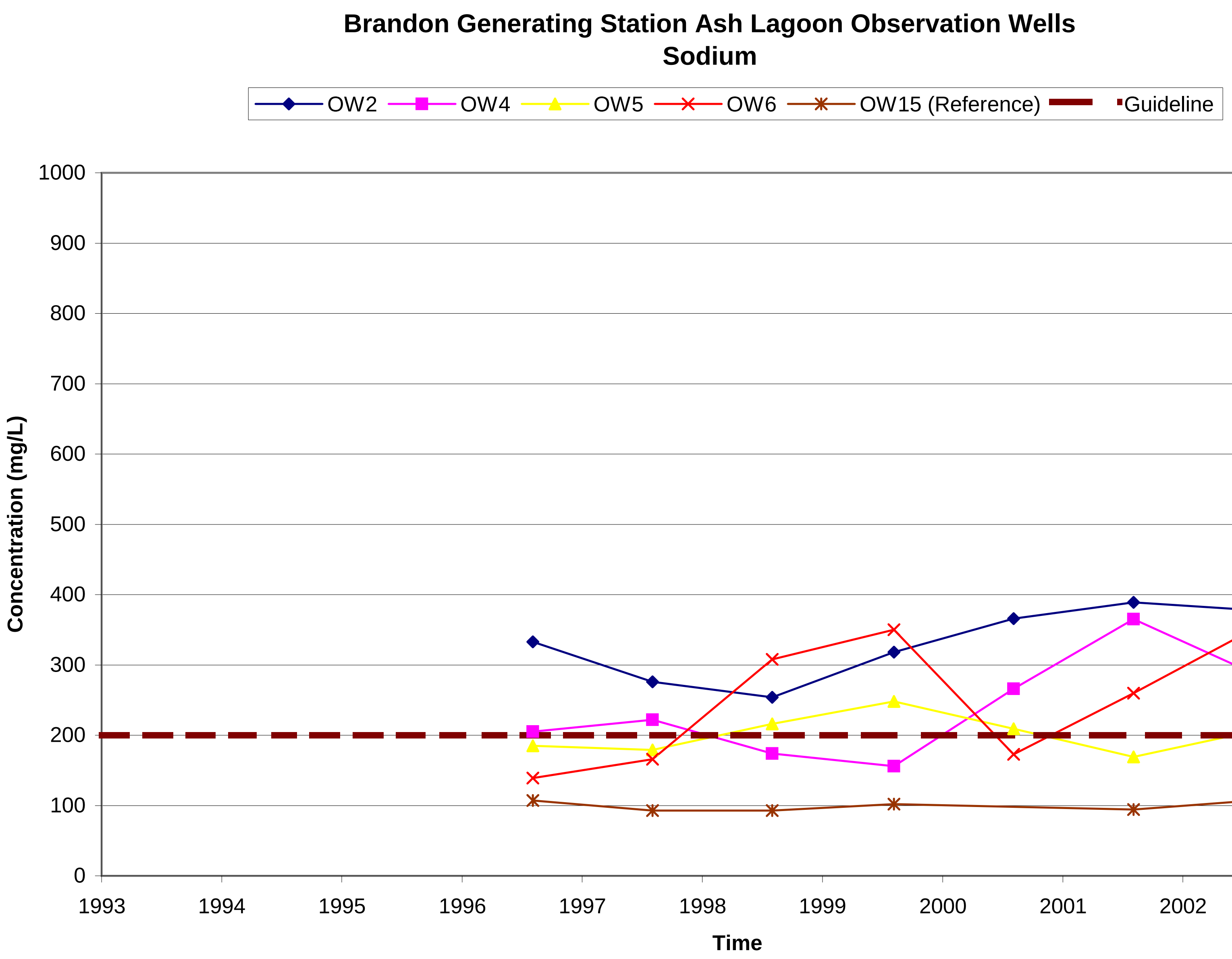

Brandon Generating Station Ash Lagoon Observation Wells
Selenium
OW8
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 32



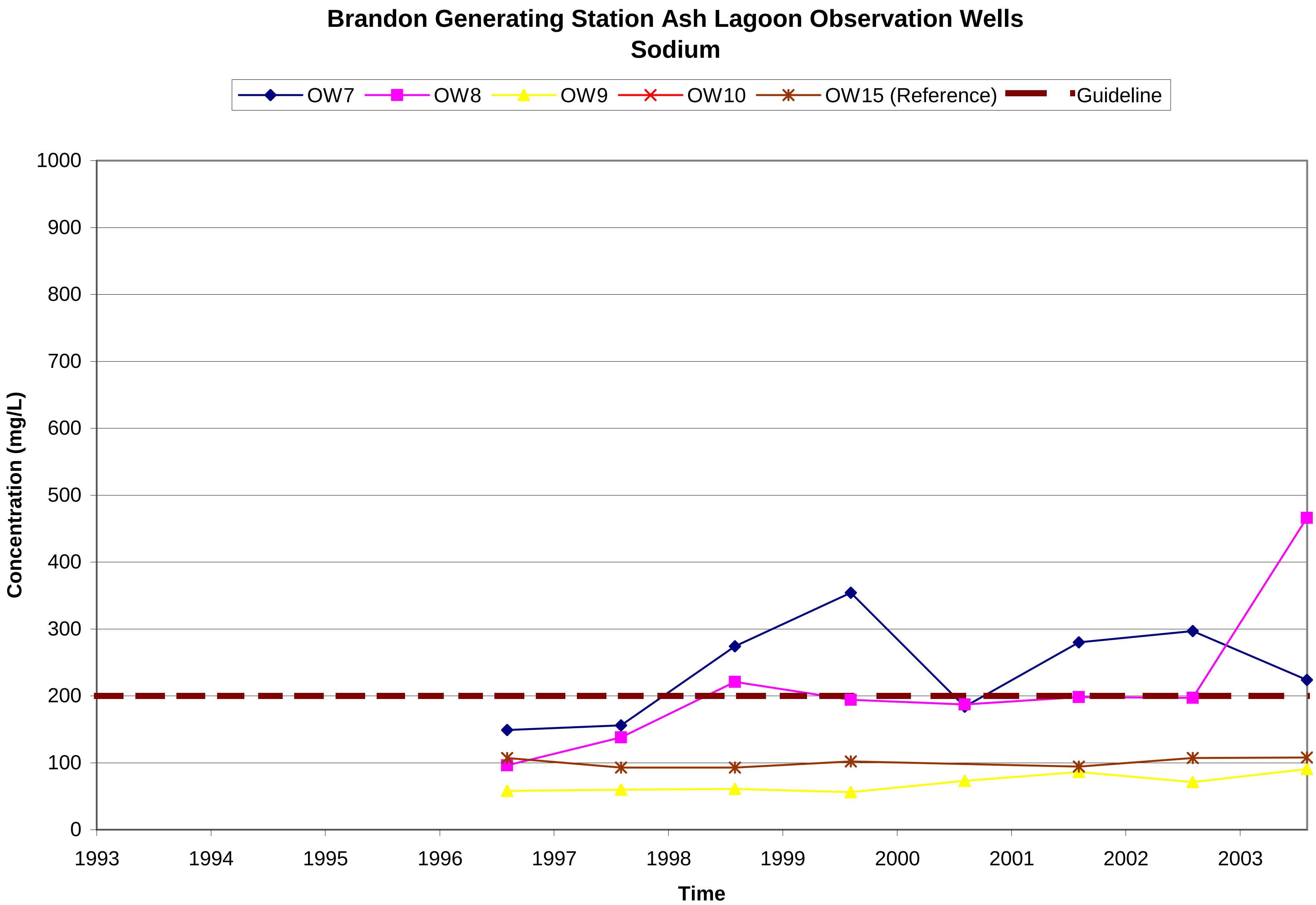
Brandon Generating Station Coal Pile Observation Wells
Selenium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
30
25
20
15
10
5
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 33



Brandon Generating Station Ash Lagoon Observation Wells
Sodium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 34



Brandon Generating Station Ash Lagoon Observation Wells
Sodium
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 35

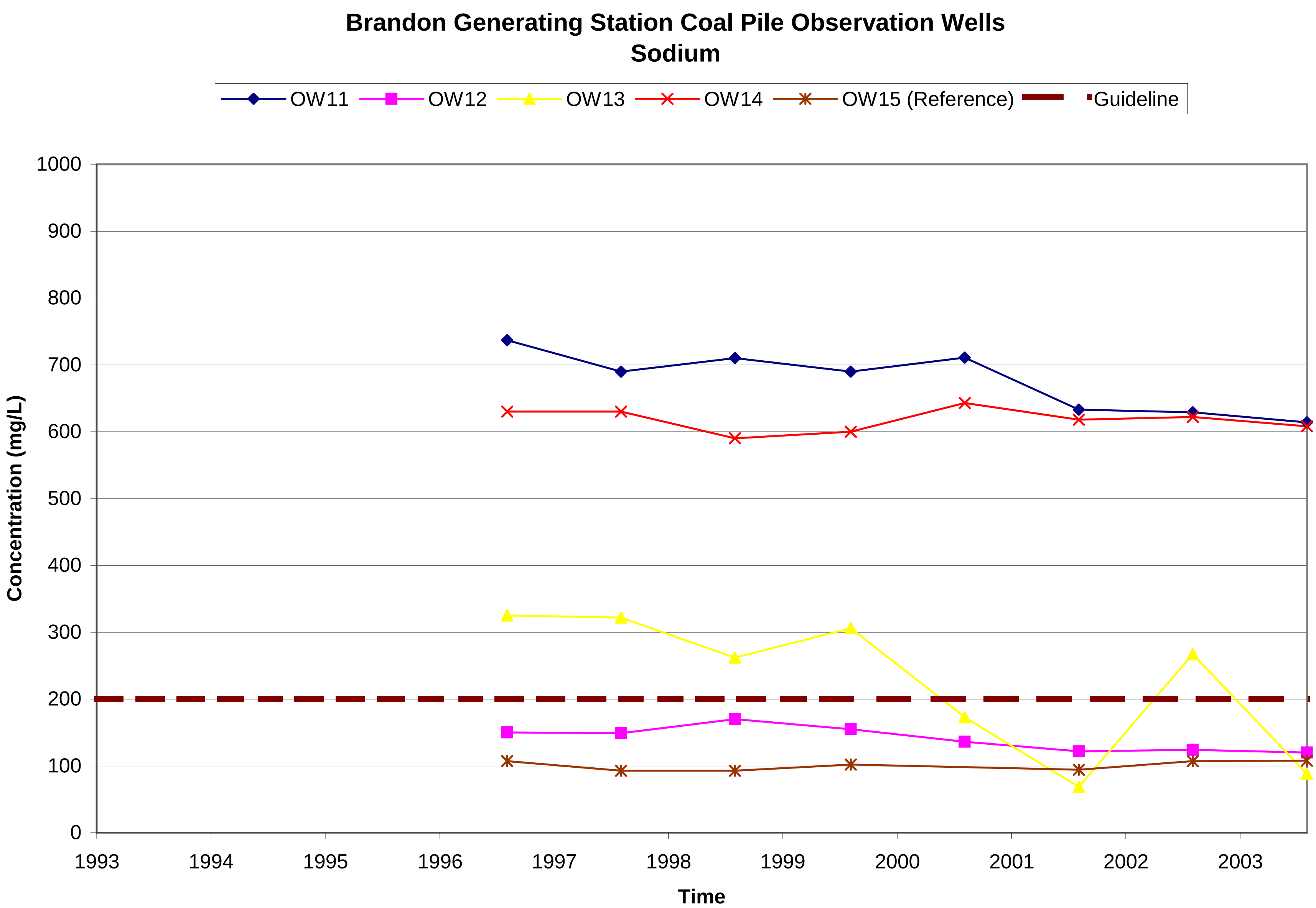

Brandon Generating Station Coal Pile Observation Wells
Sodium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure 36

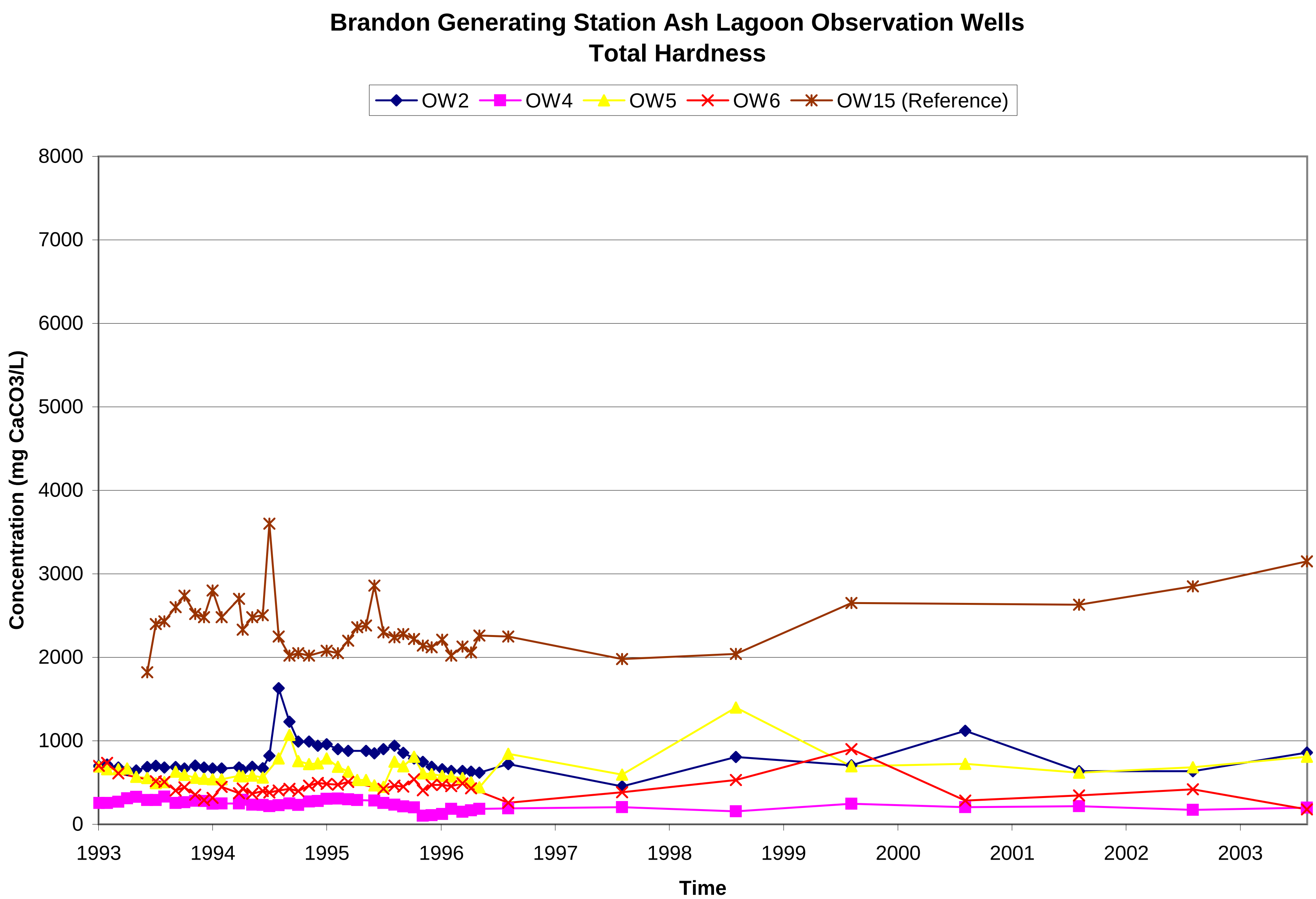

Brandon Generating Station Ash Lagoon Observation Wells
Total Hardness
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg CaCO3/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-1

Appendix A
Other Water Quality Parameters Figures

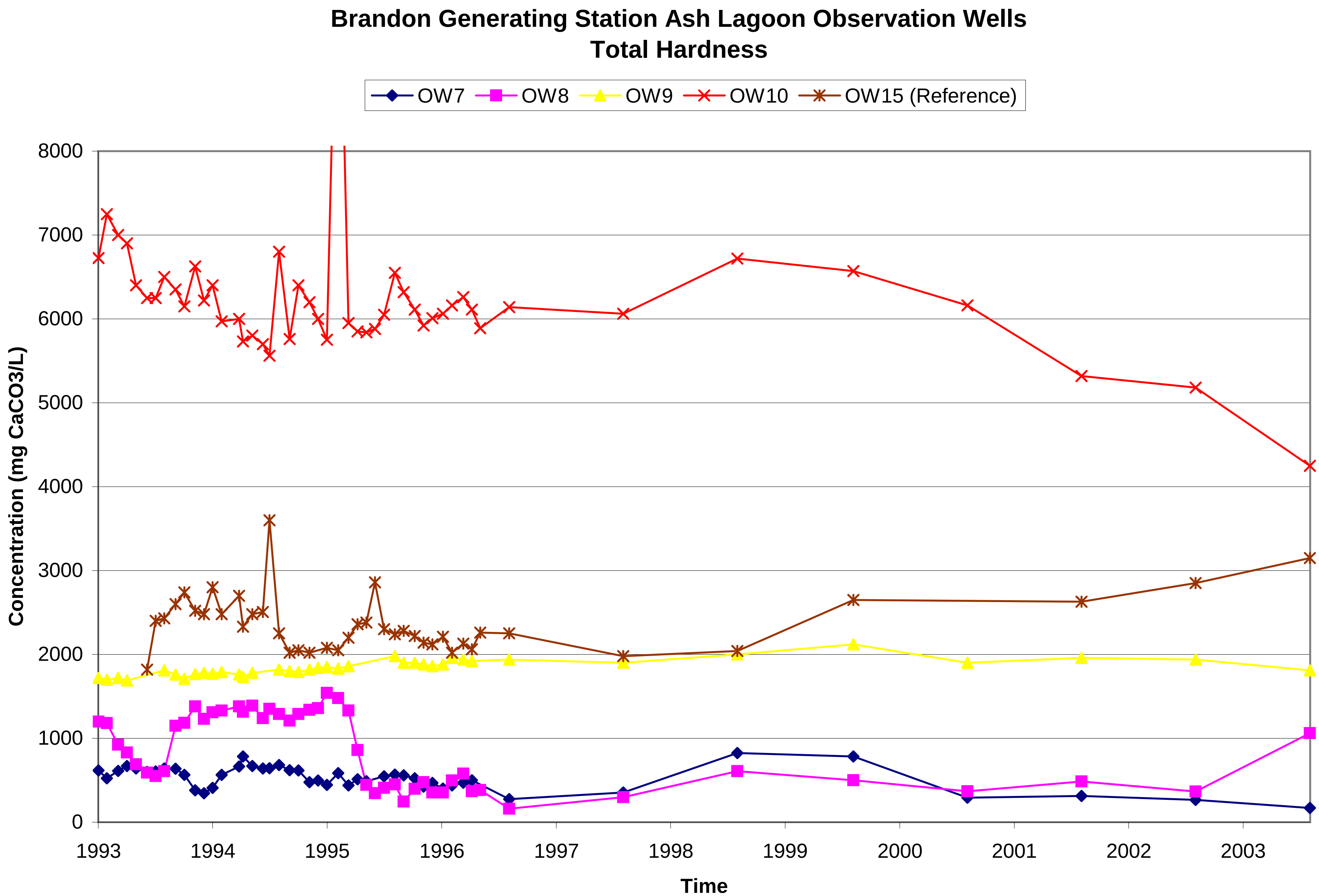

Brandon Generating Station Ash Lagoon Observation Wells
Total Hardness
OW7
OW8
OW9
OW10
OW15 (Reference)
Concentration (mg CaCO3/L)
0
1000
2000
3000
4000
5000
6000
7000
8000
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-2

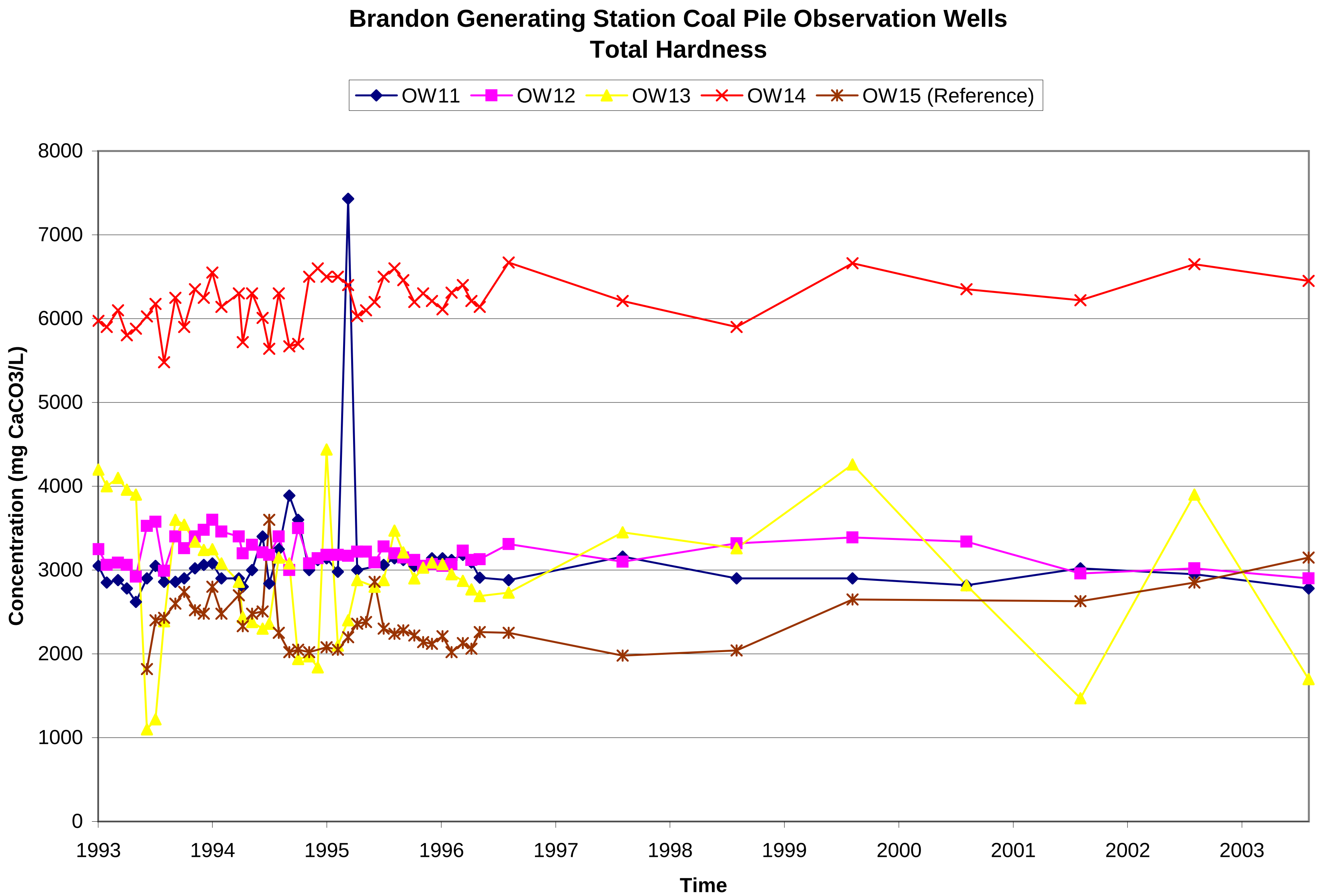

Brandon Generating Station Coal Pile Observation Wells
Total Hardness
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mg CaCO3/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-3

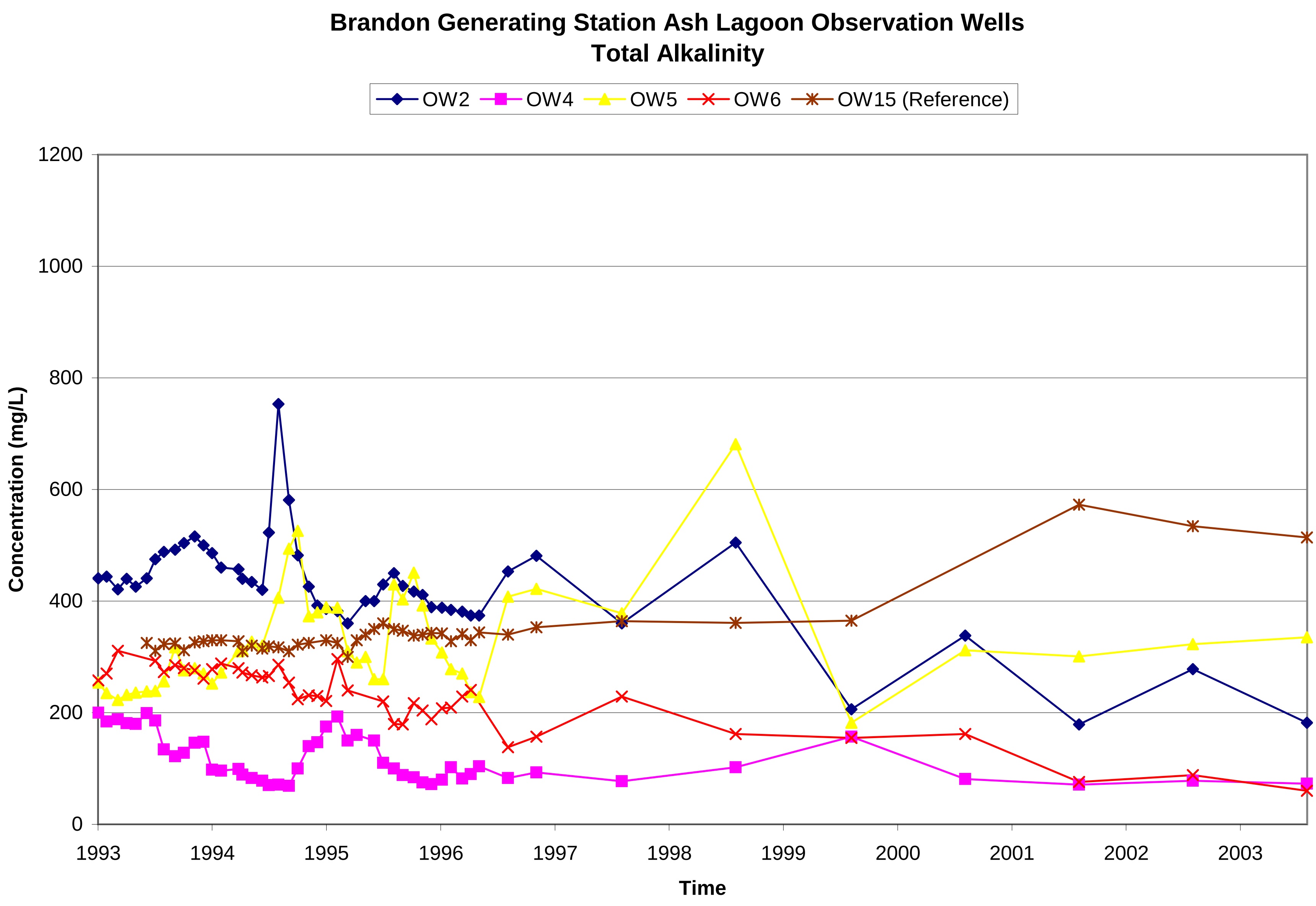

Brandon Generating Station Ash Lagoon Observation Wells
Total Alkalinity
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg/L)
0
200
400
600
800
1000
1200
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-4

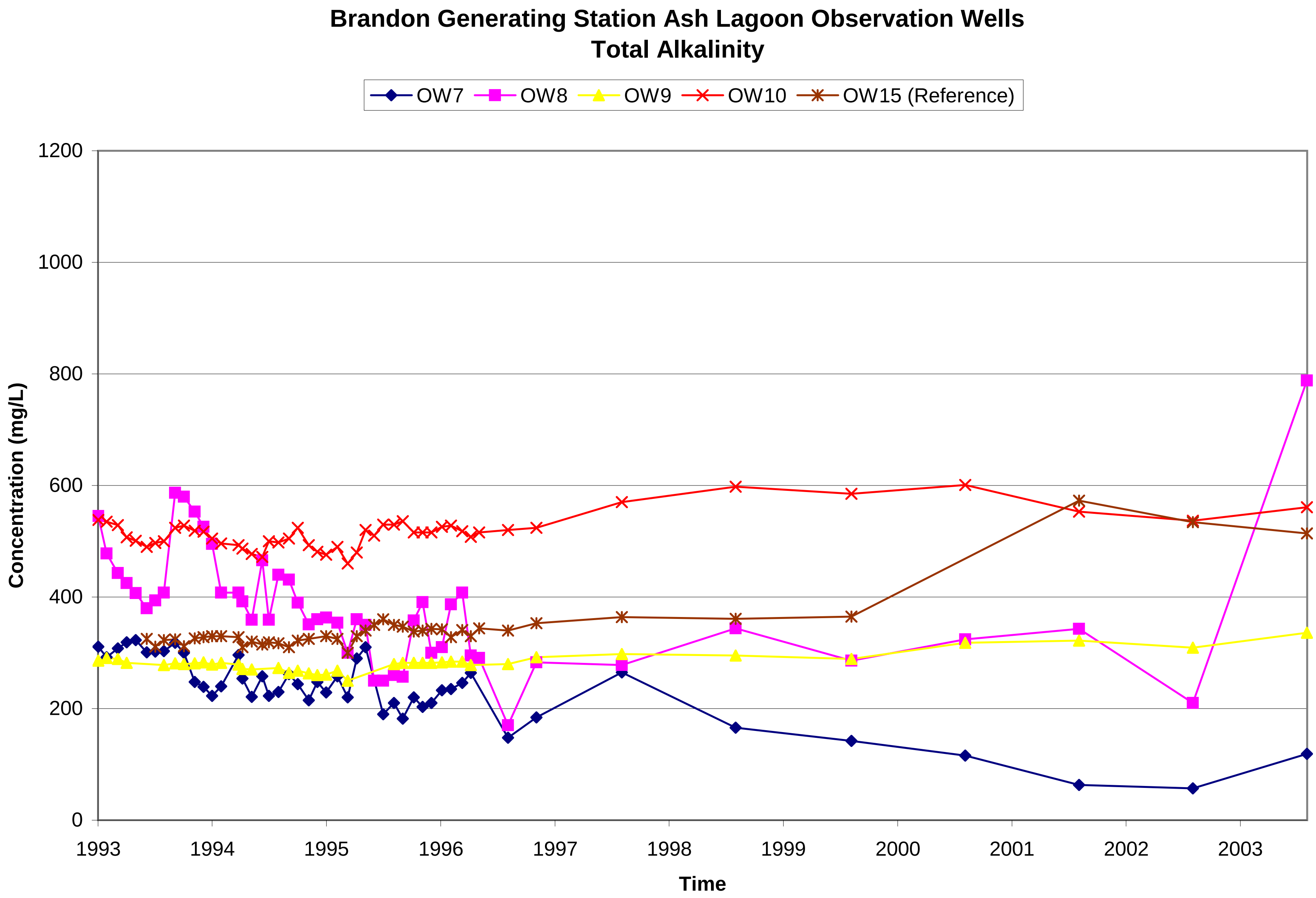

Brandon Generating Station Ash Lagoon Observation Wells
Total Alkalinity
OW7
OW8
OW9
OW10
OW15 (Reference)
Concentration (mg/L)
0
200
400
600
800
1000
1200
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-5

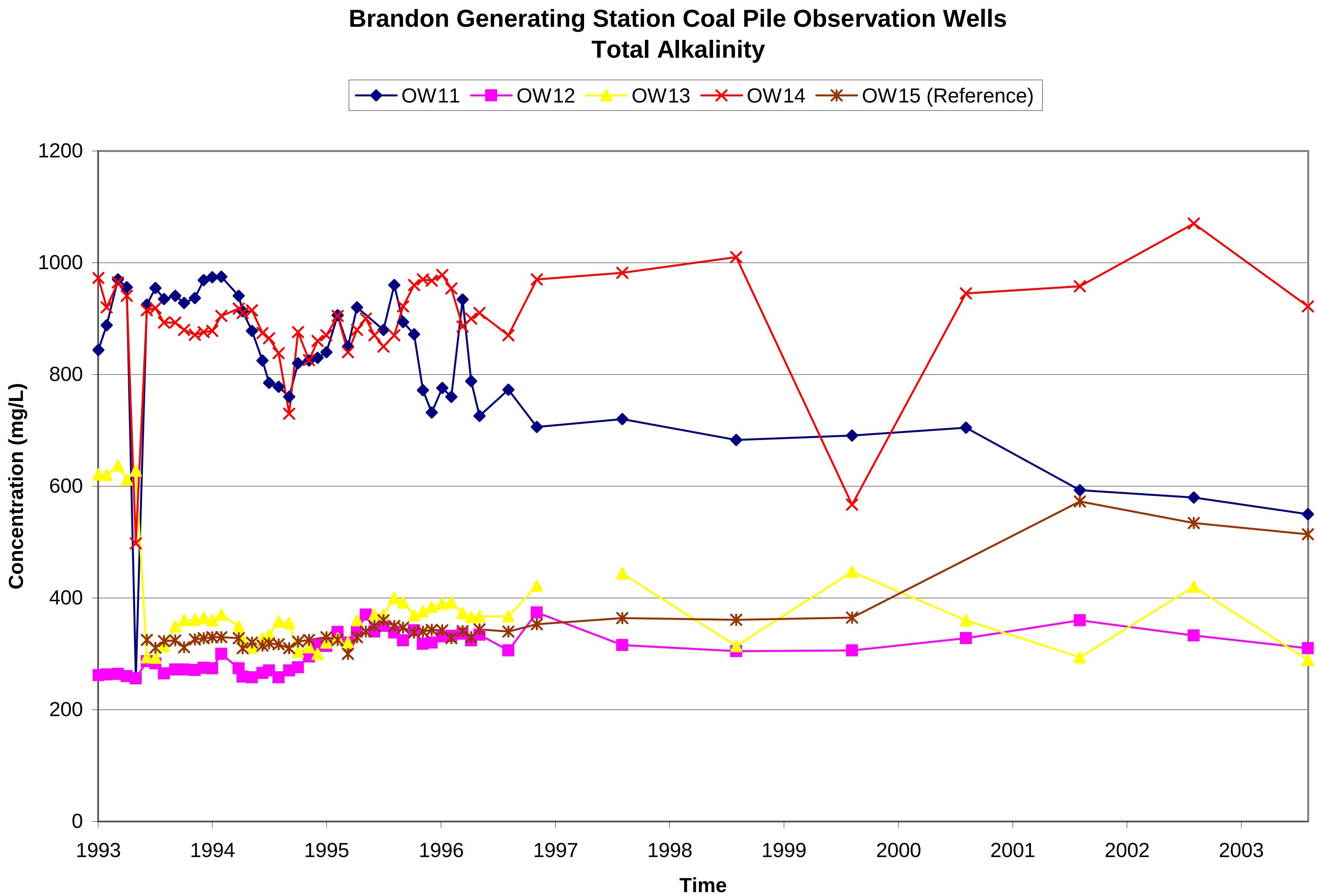
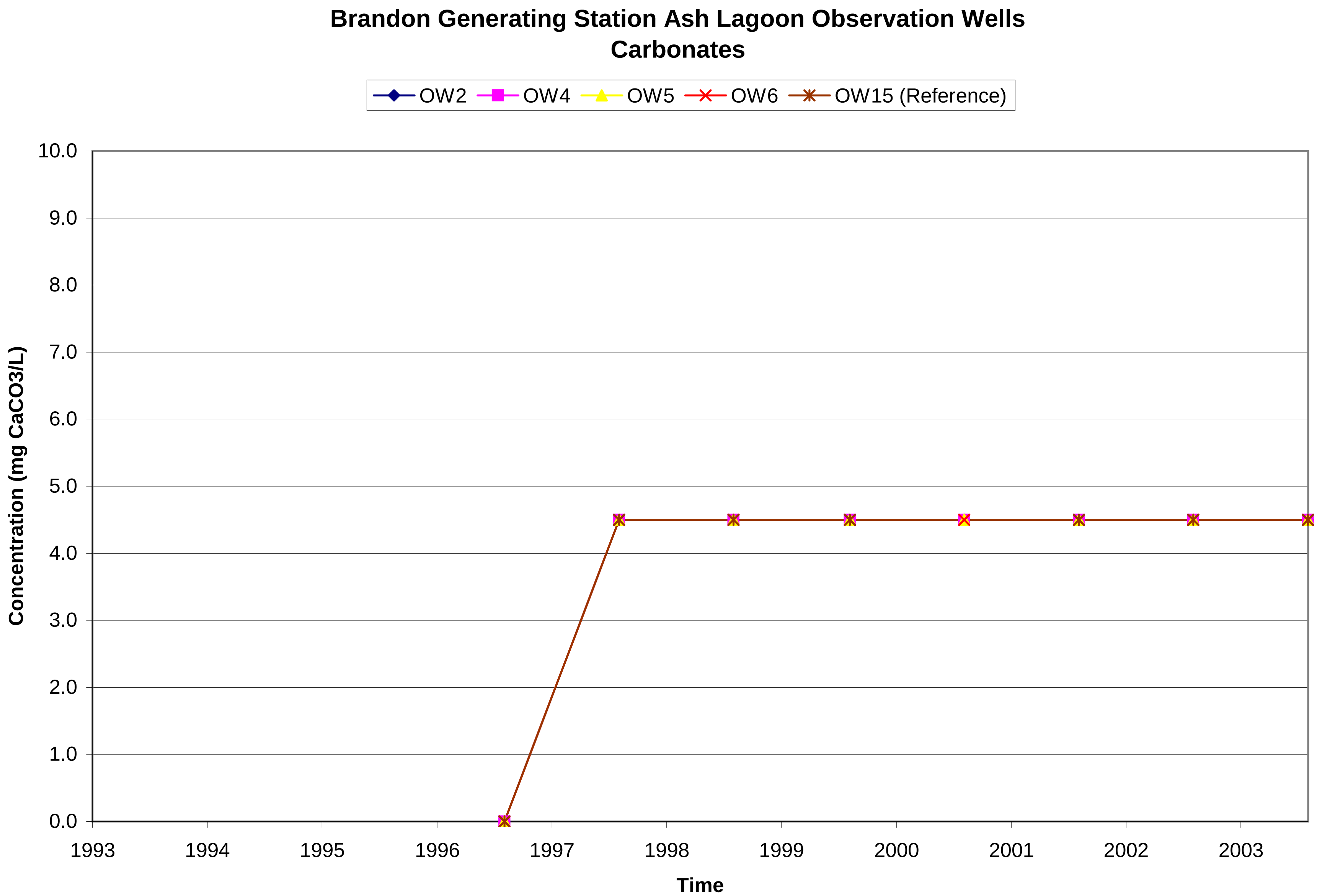

Brandon Generating Station Coal Pile Observation Wells
Total Alkalinity
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mg/L)
1200
1000
800
600
400
200
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-6



Brandon Generating Station Ash Lagoon Observation Wells
Carbonates
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg CaCO3/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-7

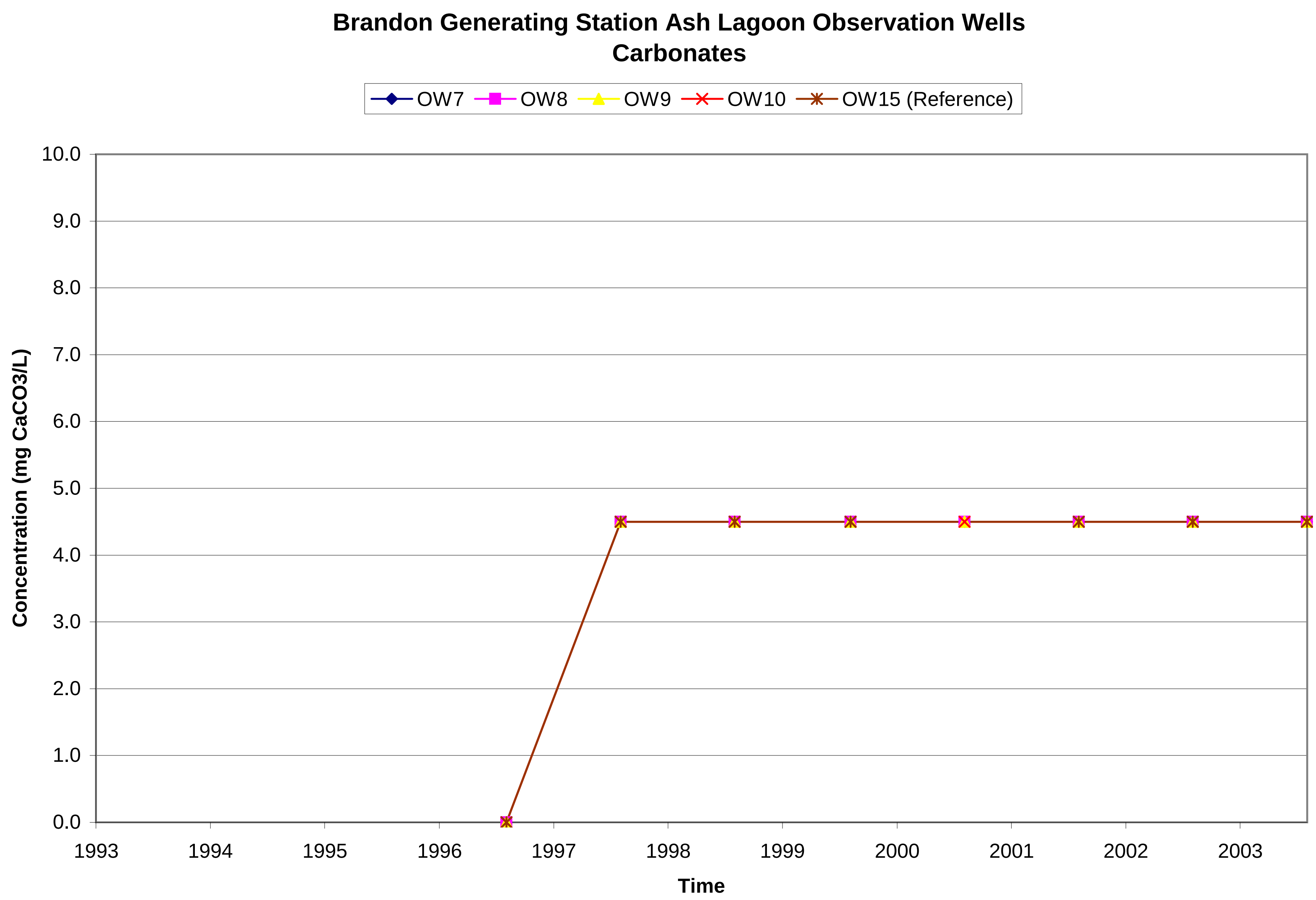

Brandon Generating Station Ash Lagoon Observation Wells
Carbonates
OW7
OW8
OW9
OW10
OW15 (Reference)
Concentration (mg CaCO3/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-8

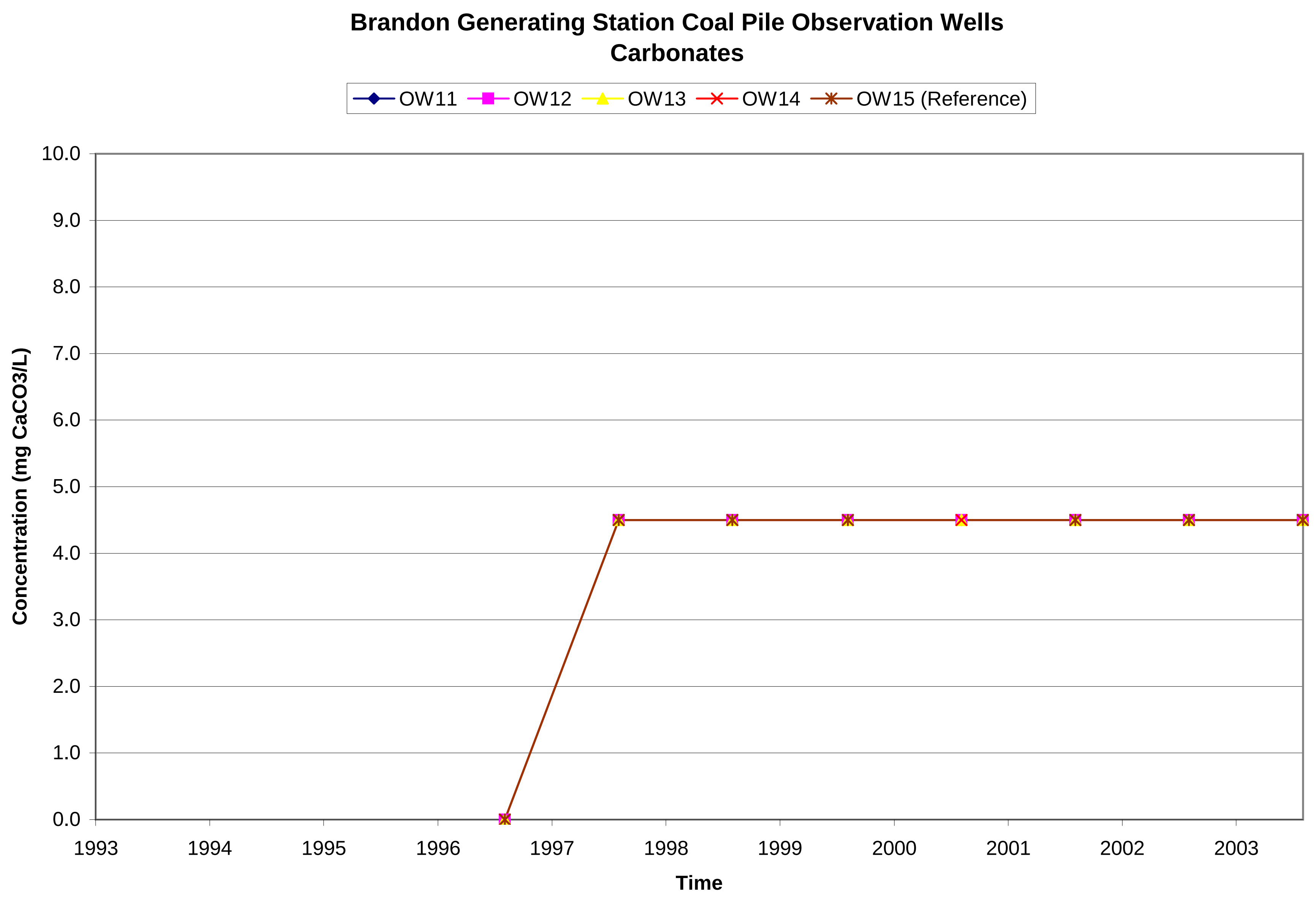

Brandon Generating Station Coal Pile Observation Wells
Carbonates
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mg CaCO3/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-9

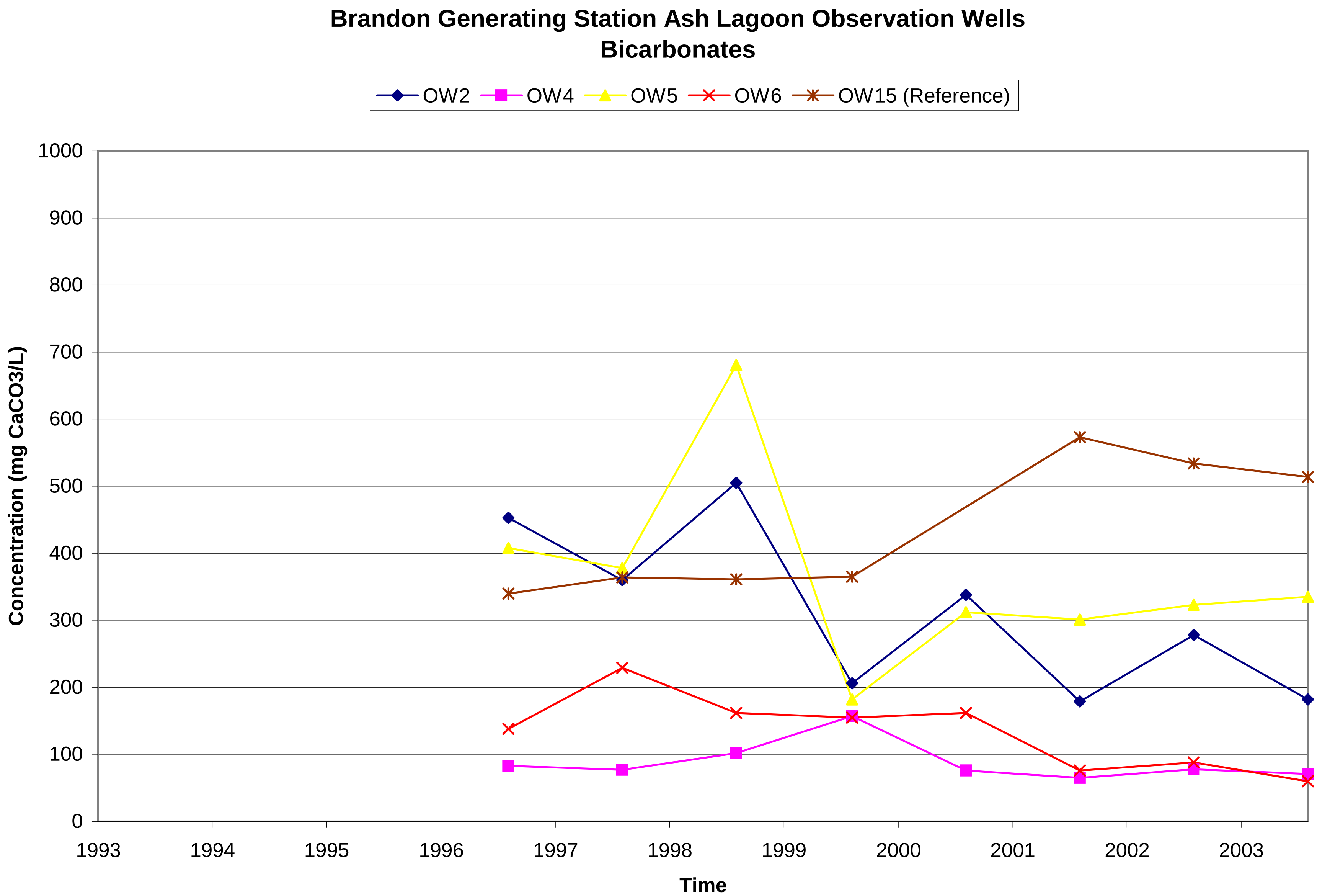
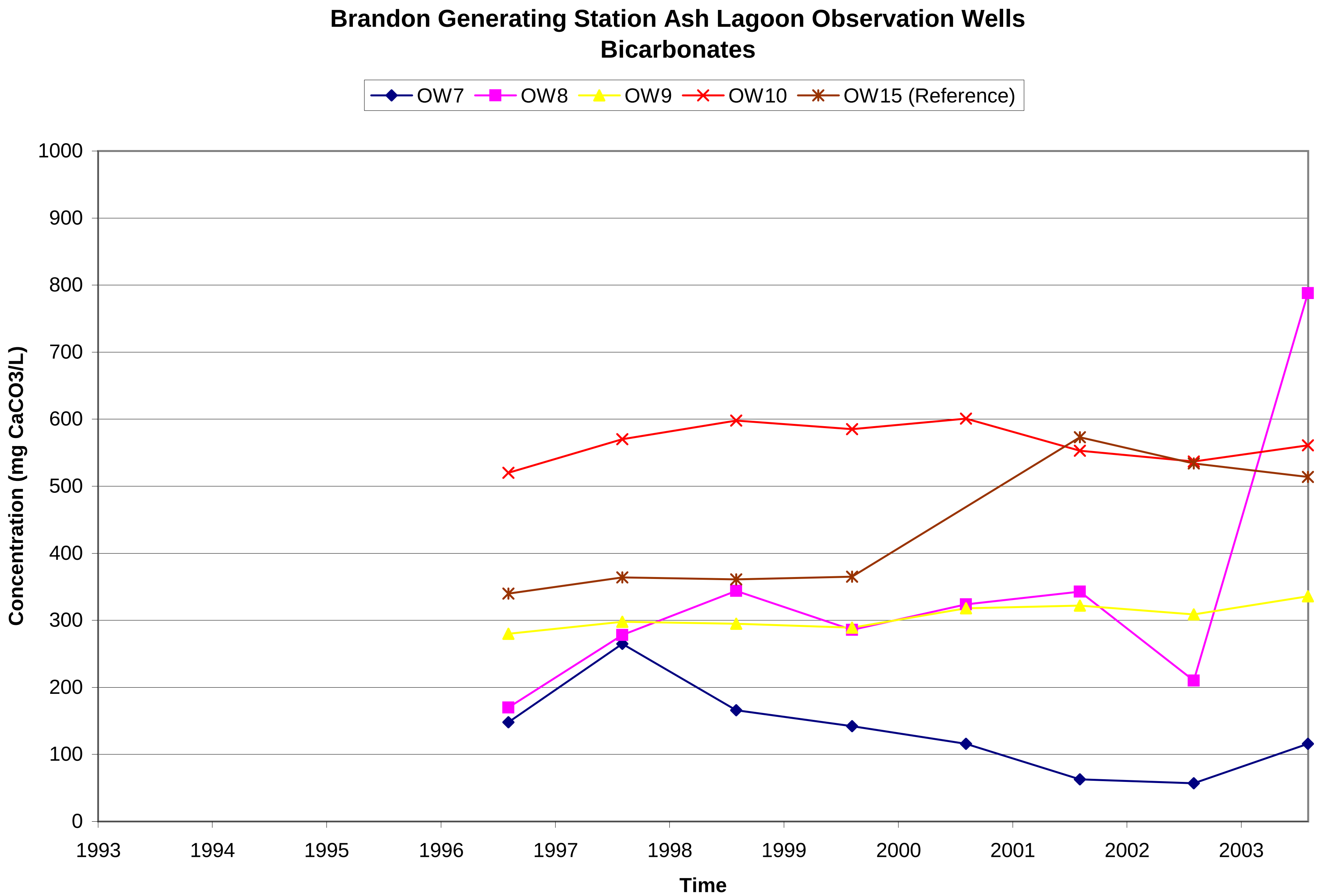

Brandon Generating Station Ash Lagoon Observation Wells
Bicarbonates
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg CaCO3/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-10



Brandon Generating Station Ash Lagoon Observation Wells
Bicarbonates
OW7
OW8
OW9
OW10
OW15 (Reference)
Concentration (mg CaCO3/L)
0
100
200
300
400
500
600
700
800
900
1000
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-11

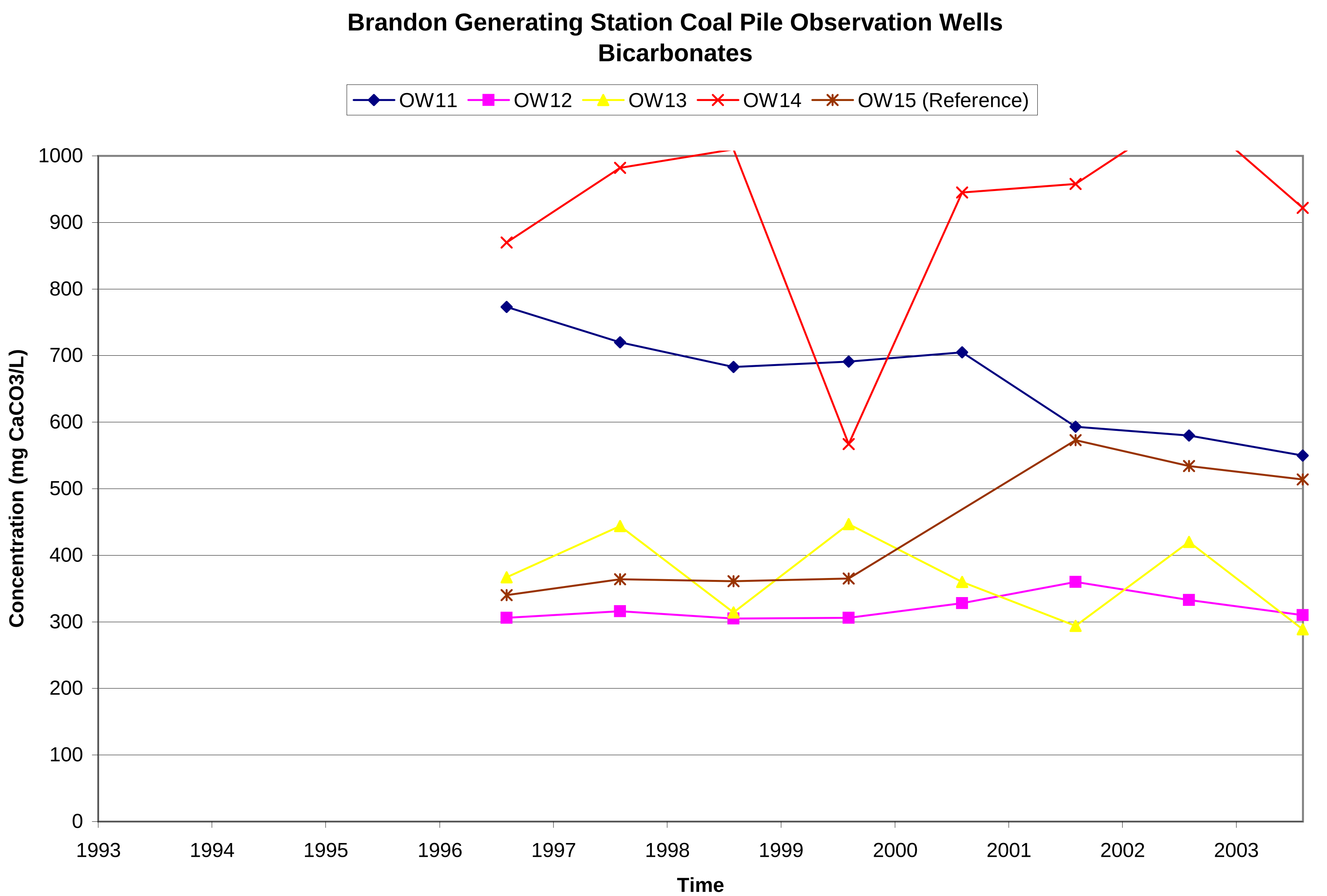

Brandon Generating Station Coal Pile Observation Wells
Bicarbonates
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mg CaCO3/L)
0
100
200
300
400
500
600
700
800
900
1000
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-12

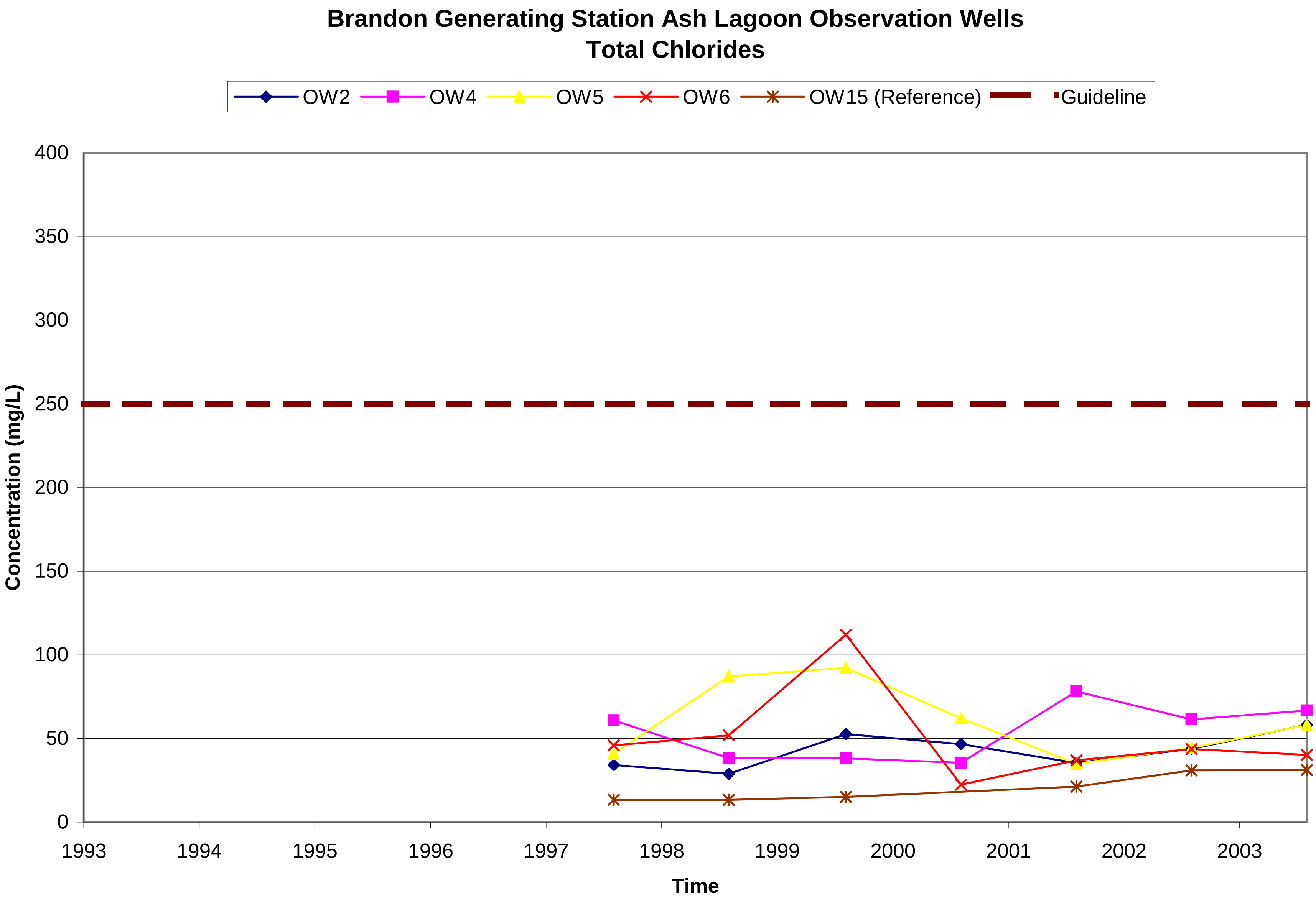

Brandon Generating Station Ash Lagoon Observation Wells
Total Chlorides
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
400
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-13

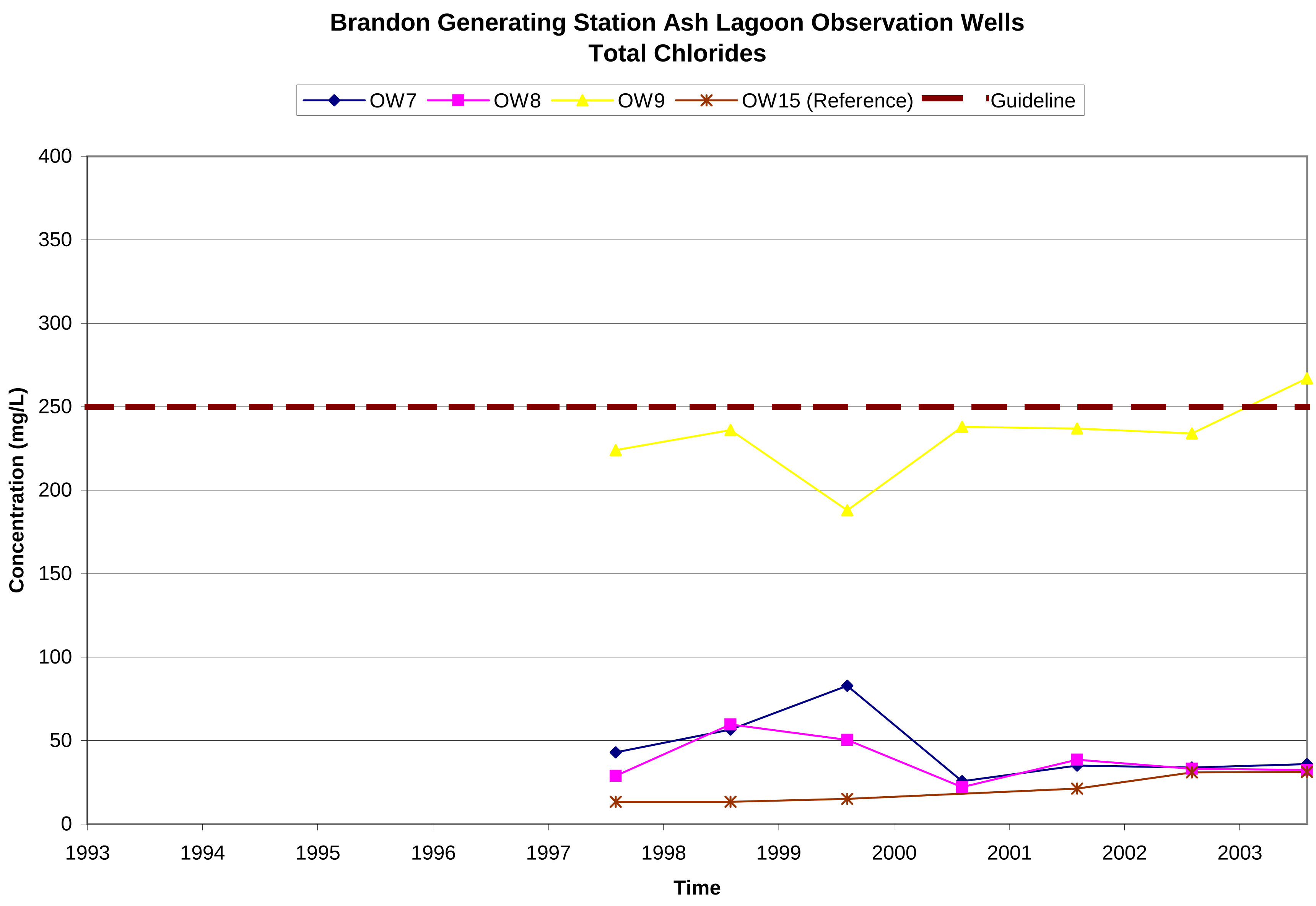
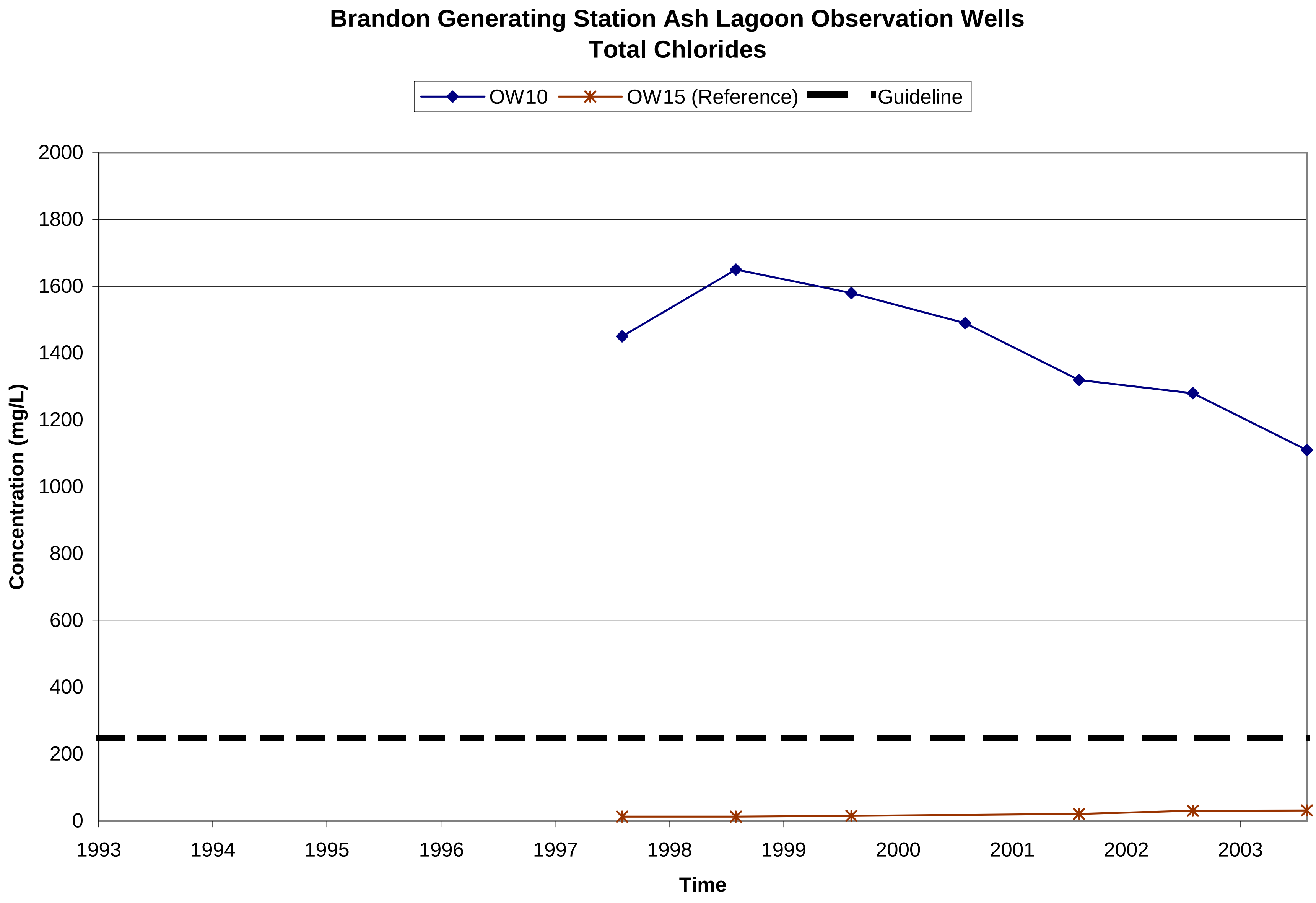

Brandon Generating Station Ash Lagoon Observation Wells
Total Chlorides
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (mg/L)
400
350
300
250
200
150
100
50
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-14



Brandon Generating Station Ash Lagoon Observation Wells
Total Chlorides
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-15

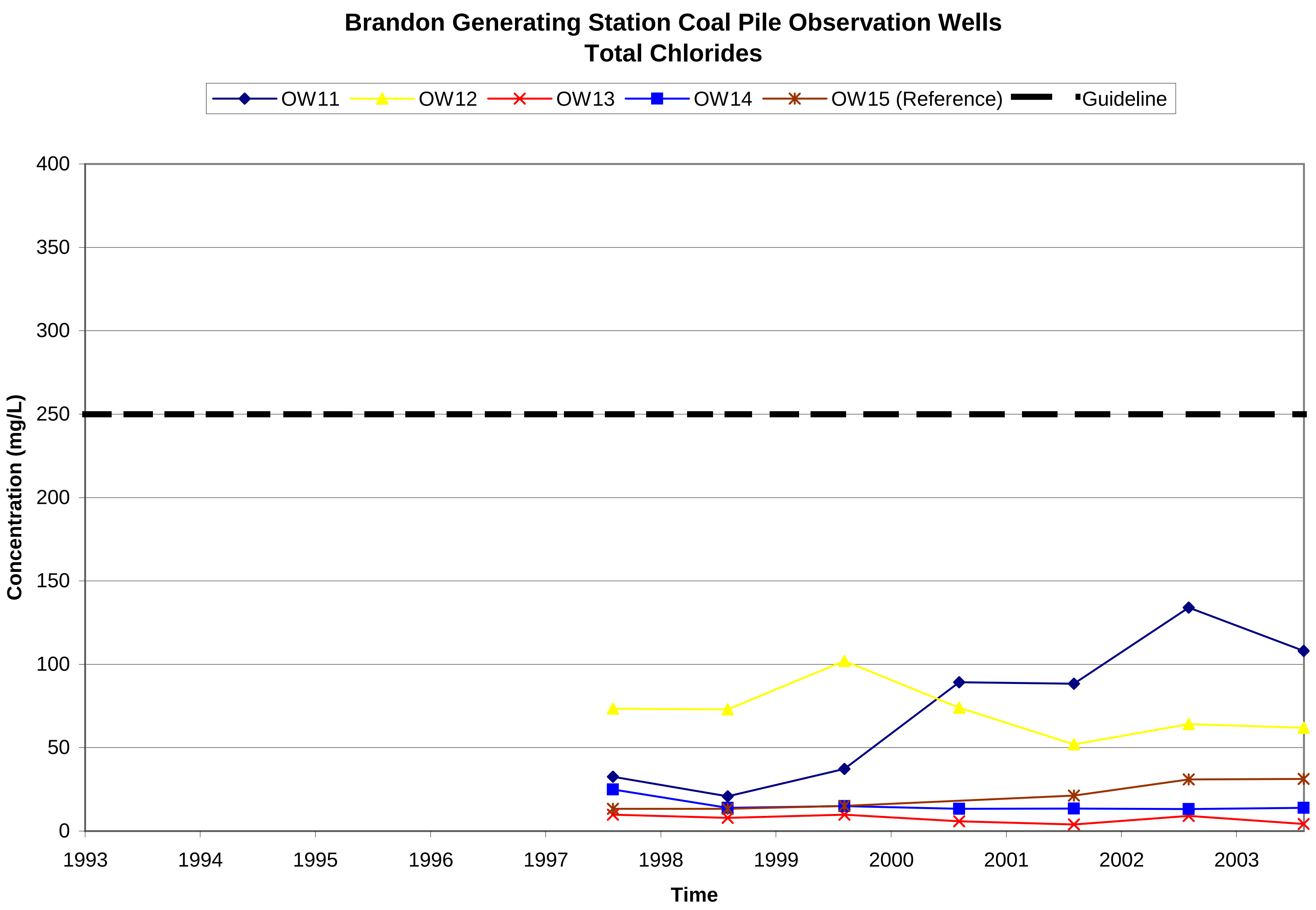

Brandon Generating Station Coal Pile Observation Wells
Total Chlorides
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
400
350
300
250
200
150
100
50
0
Concentration (mg/L)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-16

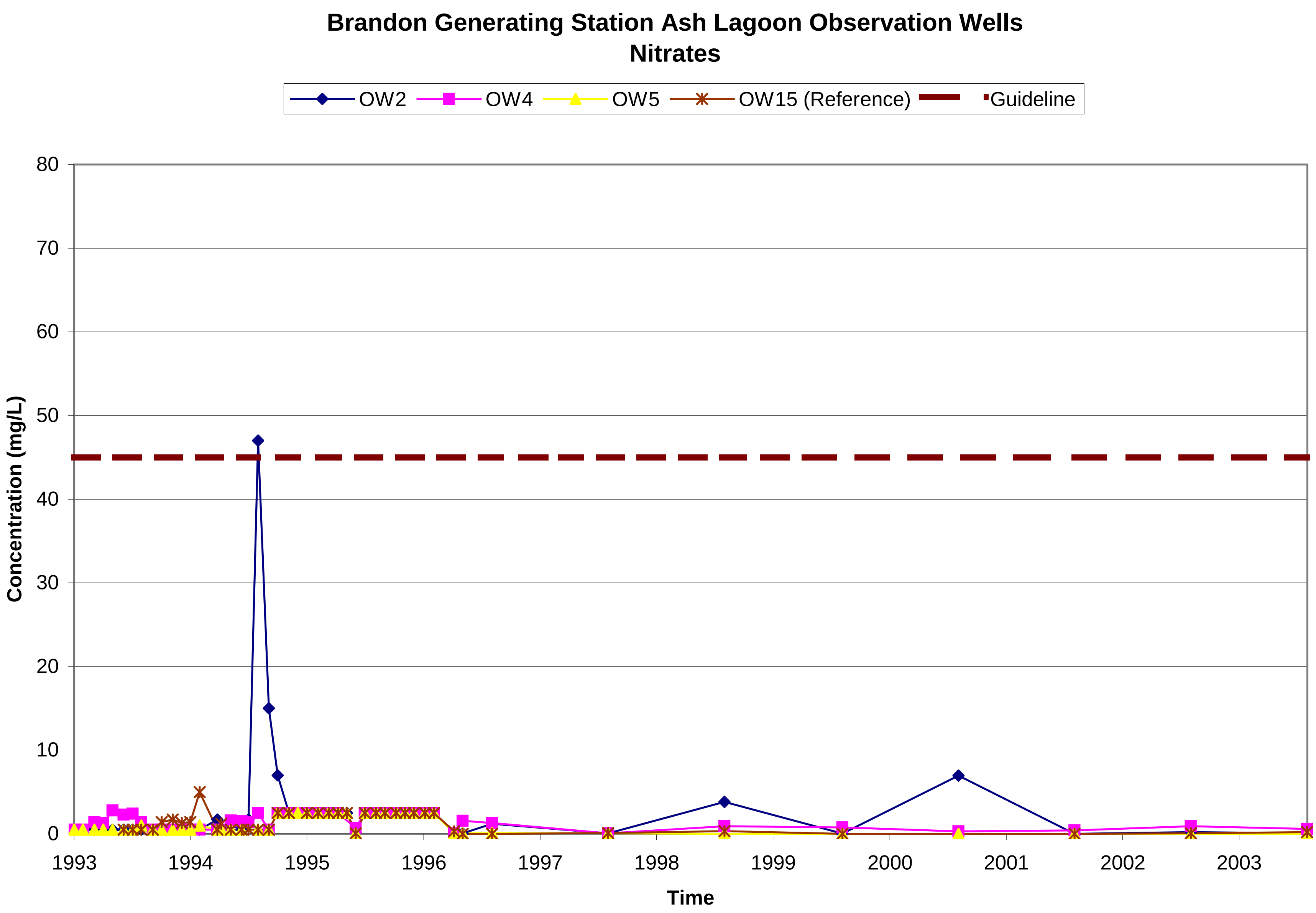

Brandon Generating Station Ash Lagoon Observation Wells
Nitrates
OW2
OW4
OW5
OW15 (Reference)
Guideline
Concentration (mg/L)
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-17

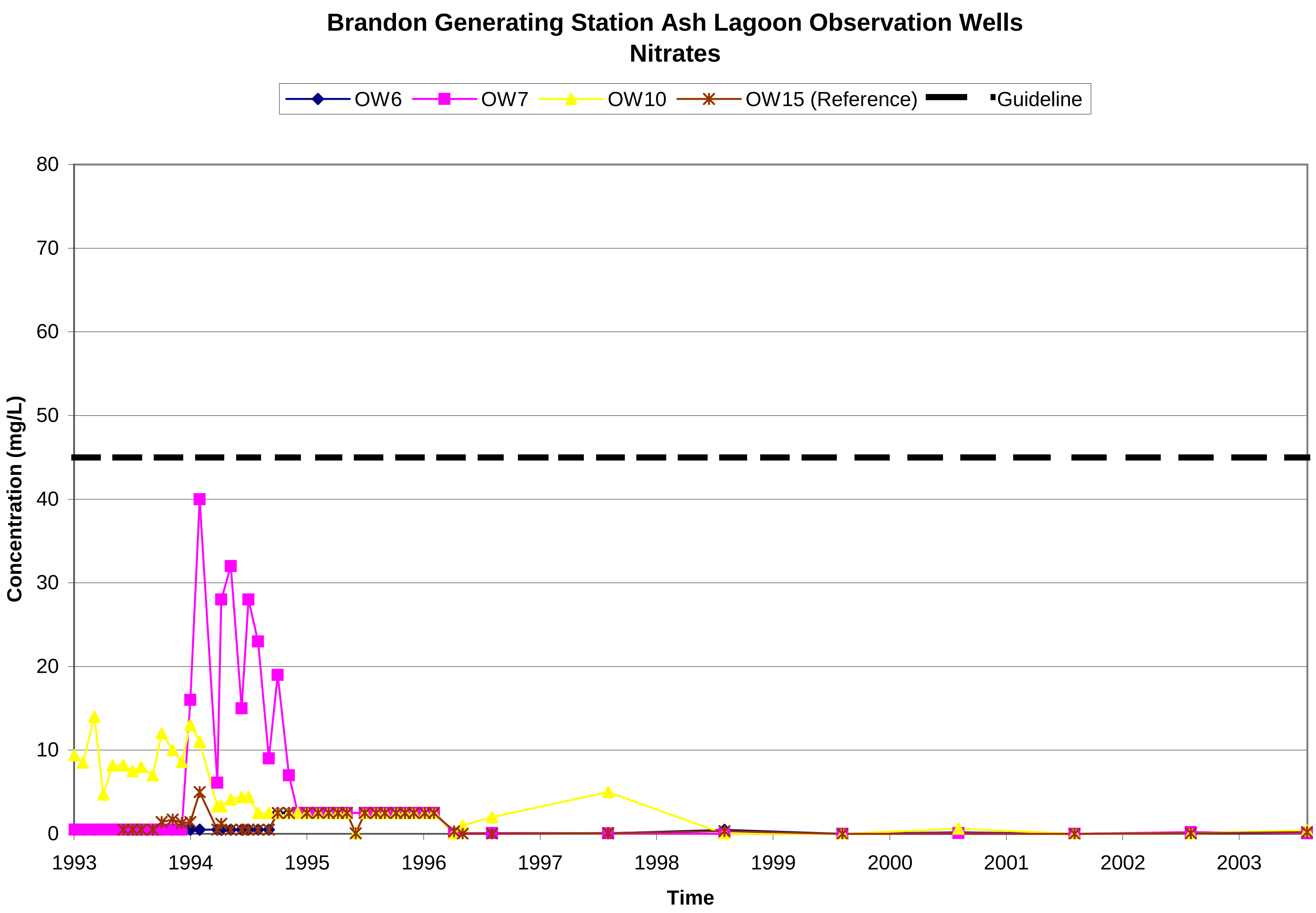
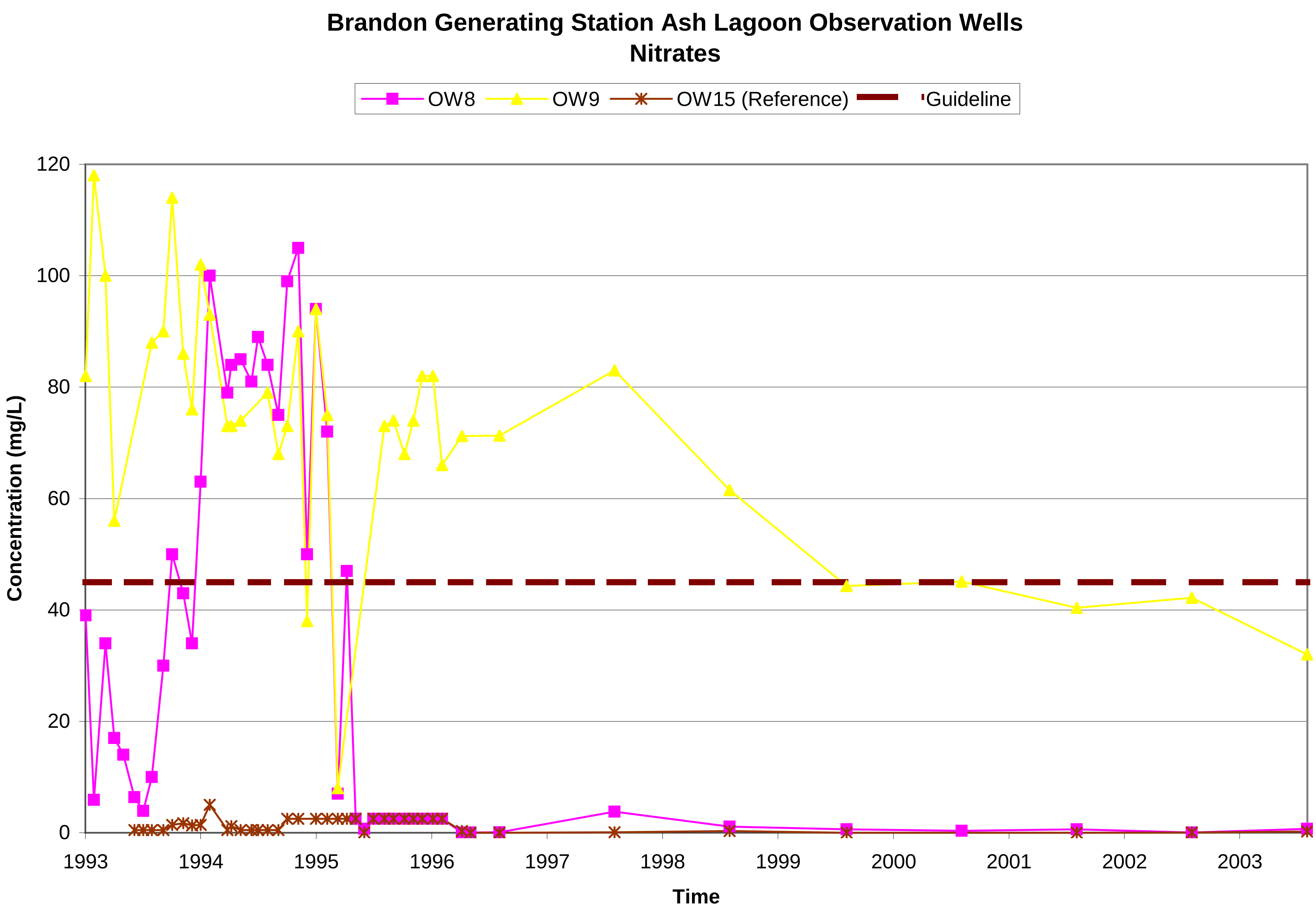
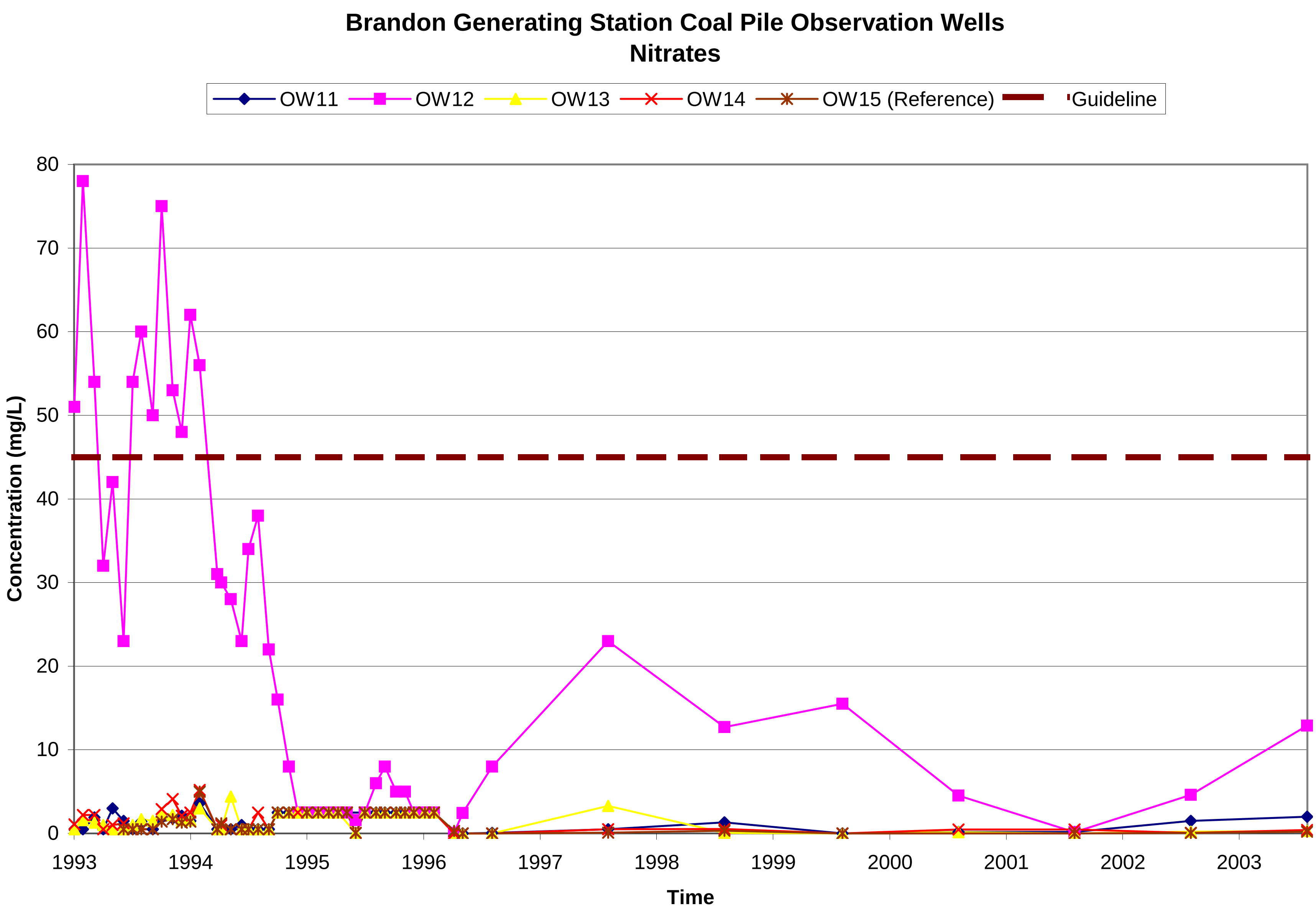

Brandon Generating Station Ash Lagoon Observation Wells
Nitrates
OW6
OW7
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
0
10
20
30
40
50
60
70
80
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-18



Brandon Generating Station Ash Lagoon Observation Wells
Nitrates
OW8
OW9
OW15 (Reference)
Guideline
Concentration (mg/L)
120
100
80
60
40
20
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-19



Brandon Generating Station Coal Pile Observation Wells
Nitrates
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-20

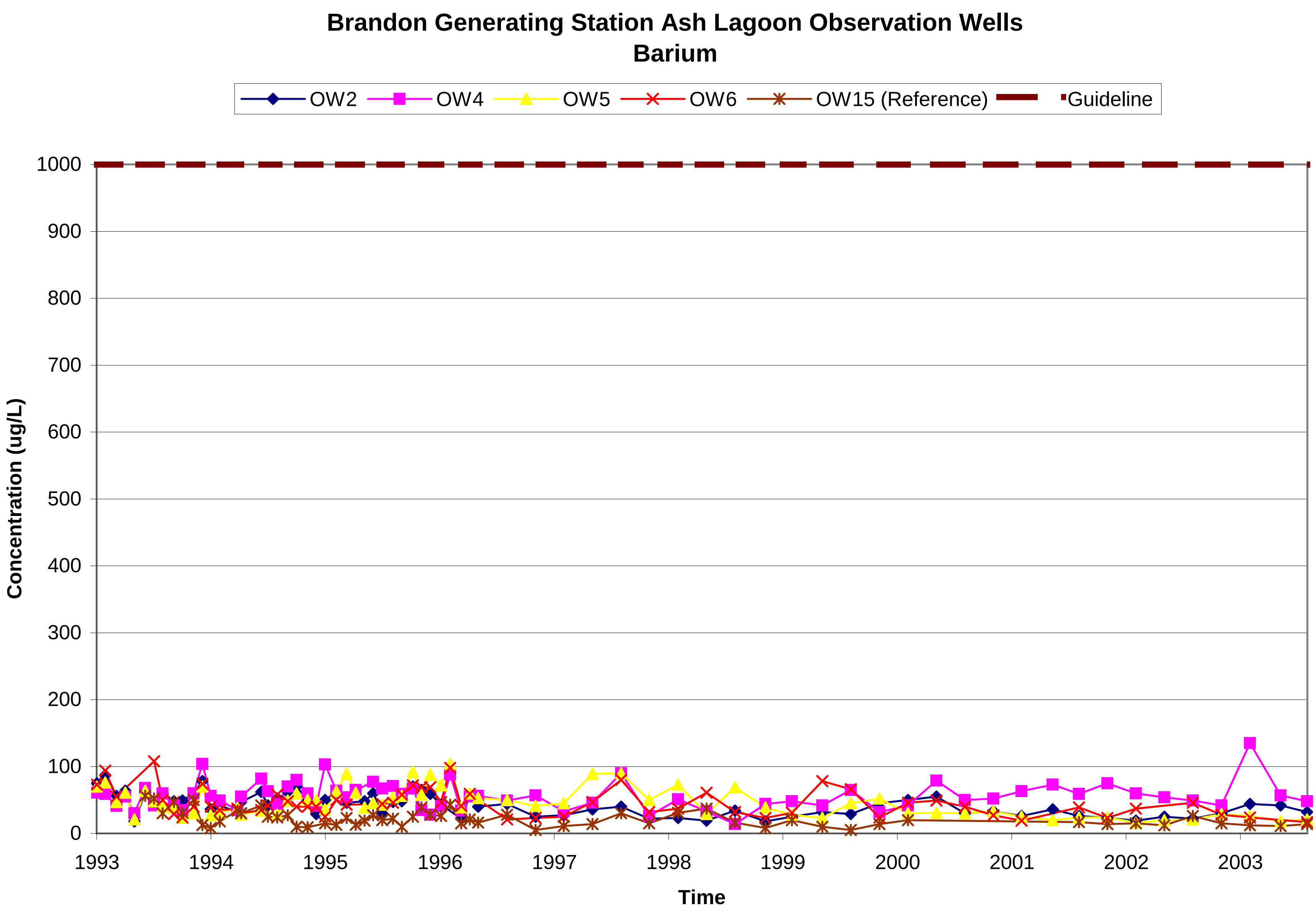

Brandon Generating Station Ash Lagoon Observation Wells
Barium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
1000
900
800
700
600
500
400
300
200
100
0
Concentration (ug/L)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-21

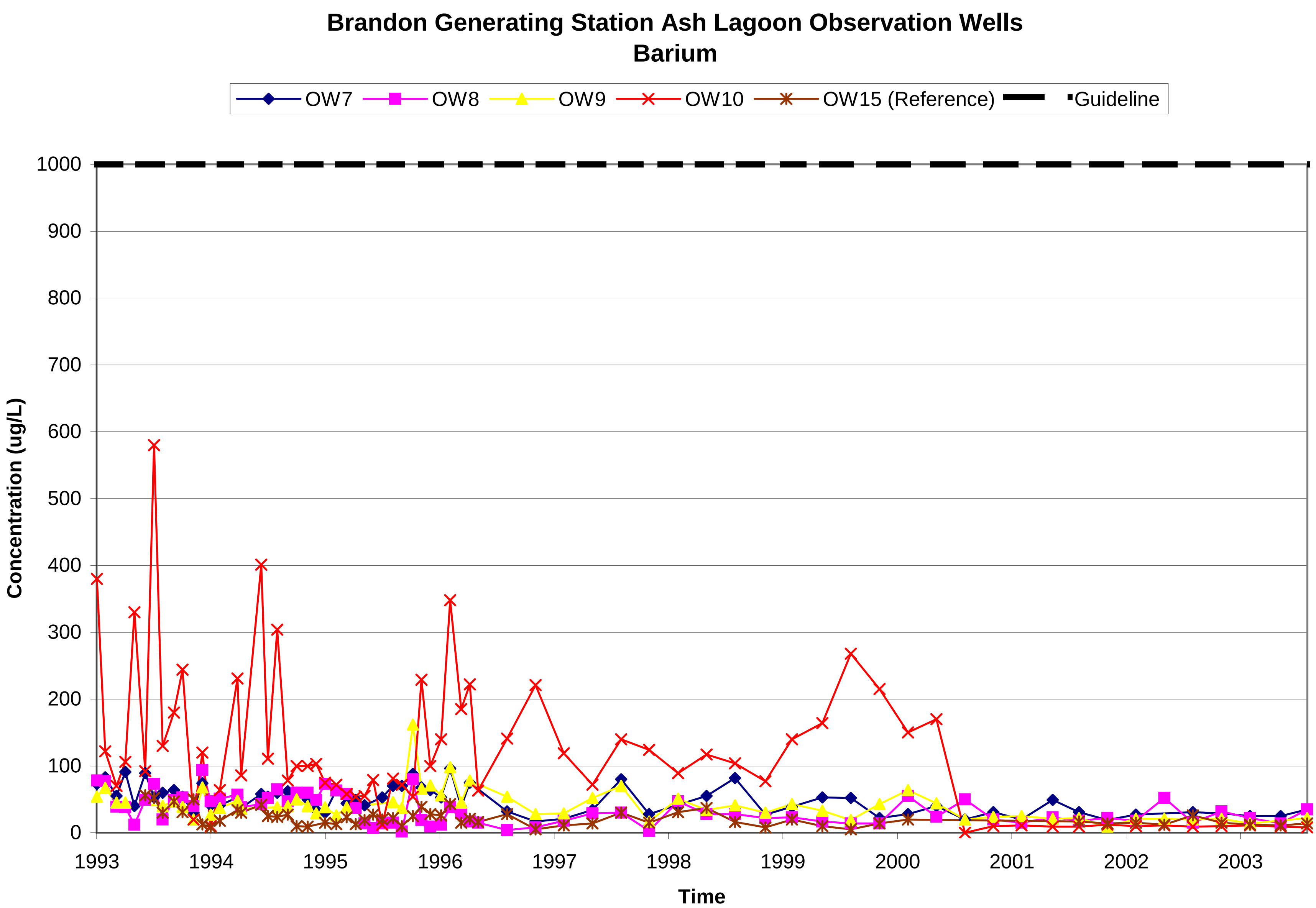
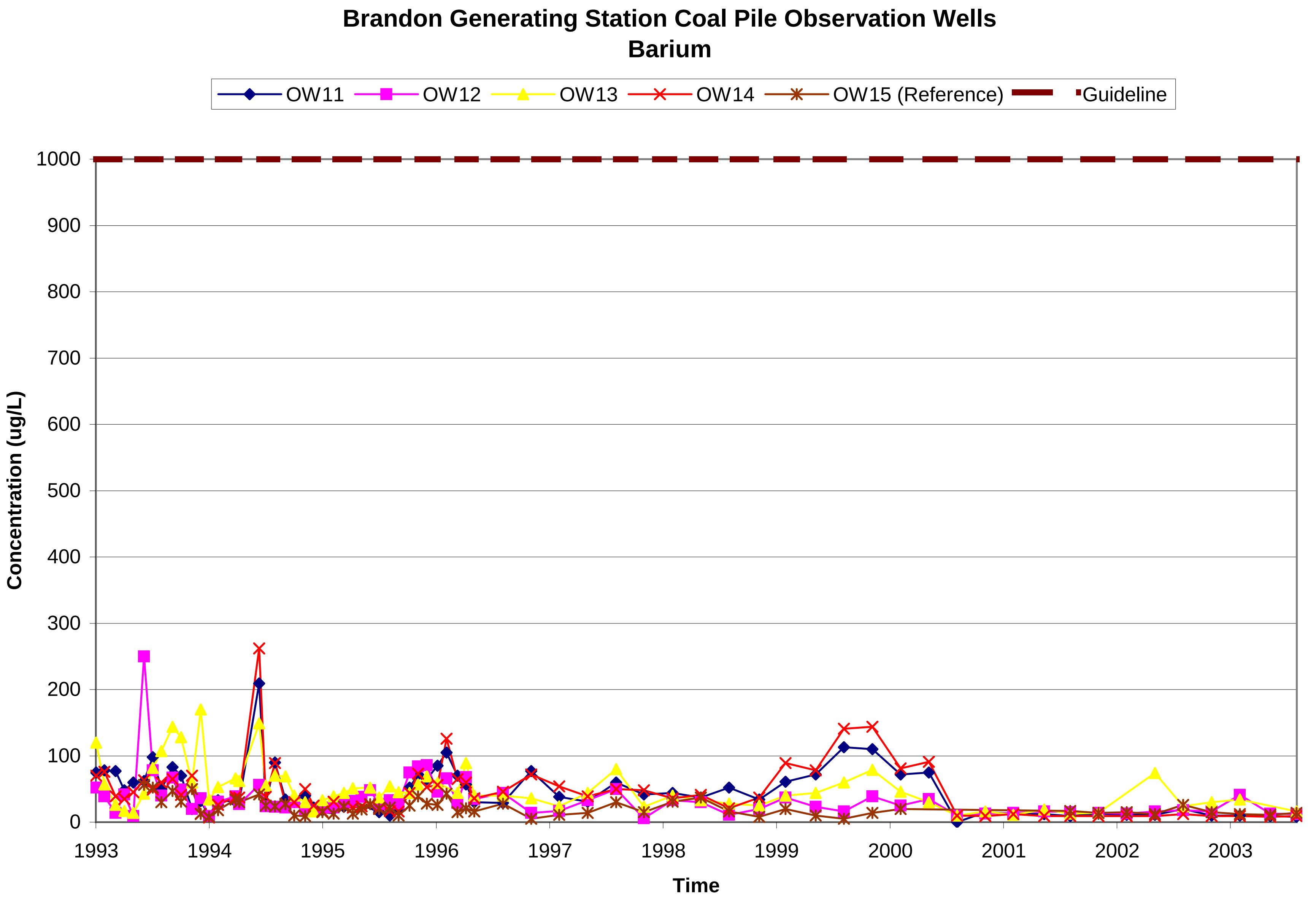

Brandon Generating Station Ash Lagoon Observation Wells
Barium
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-22



Brandon Generating Station Coal Pile Observation Wells
Barium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-23

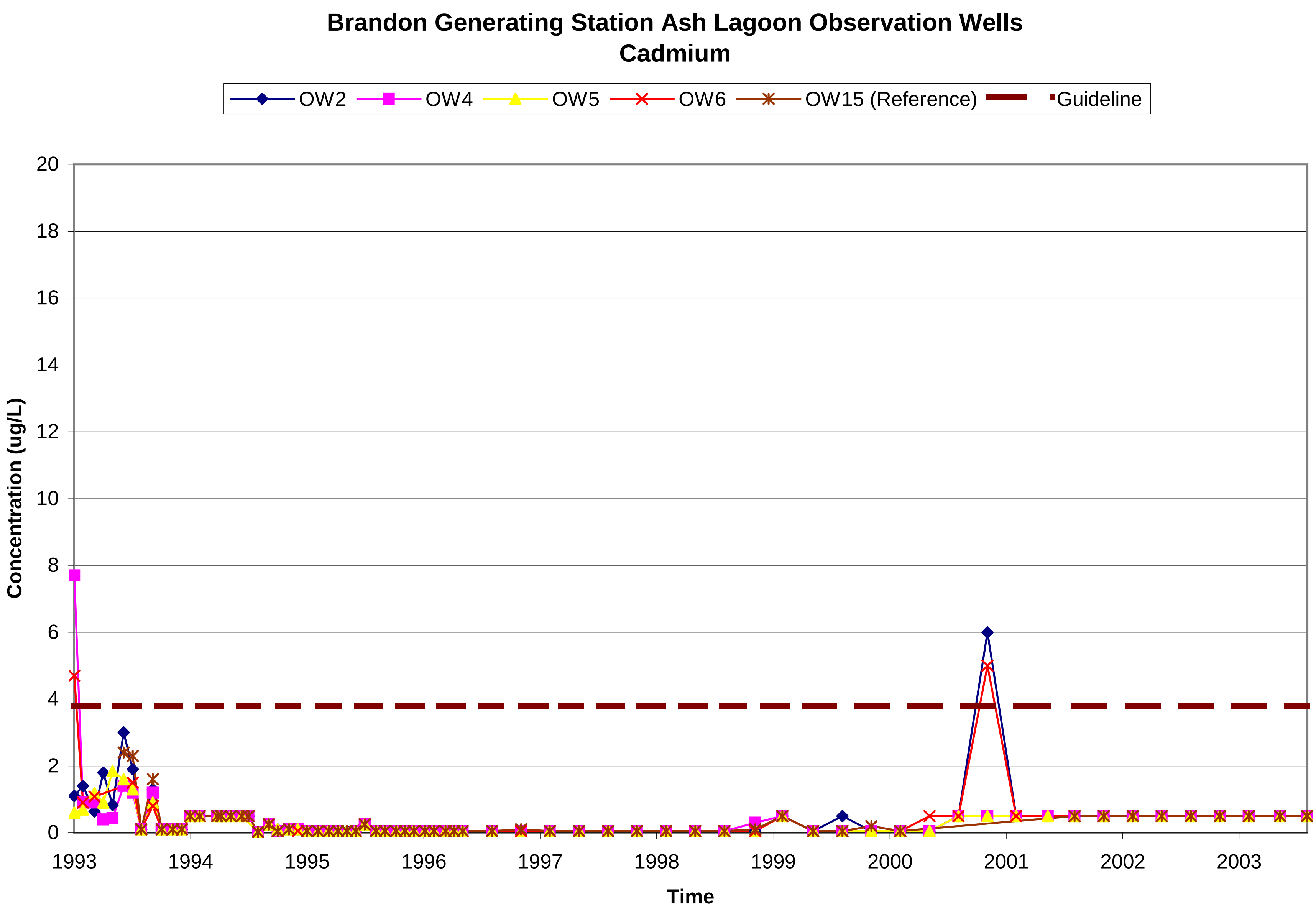
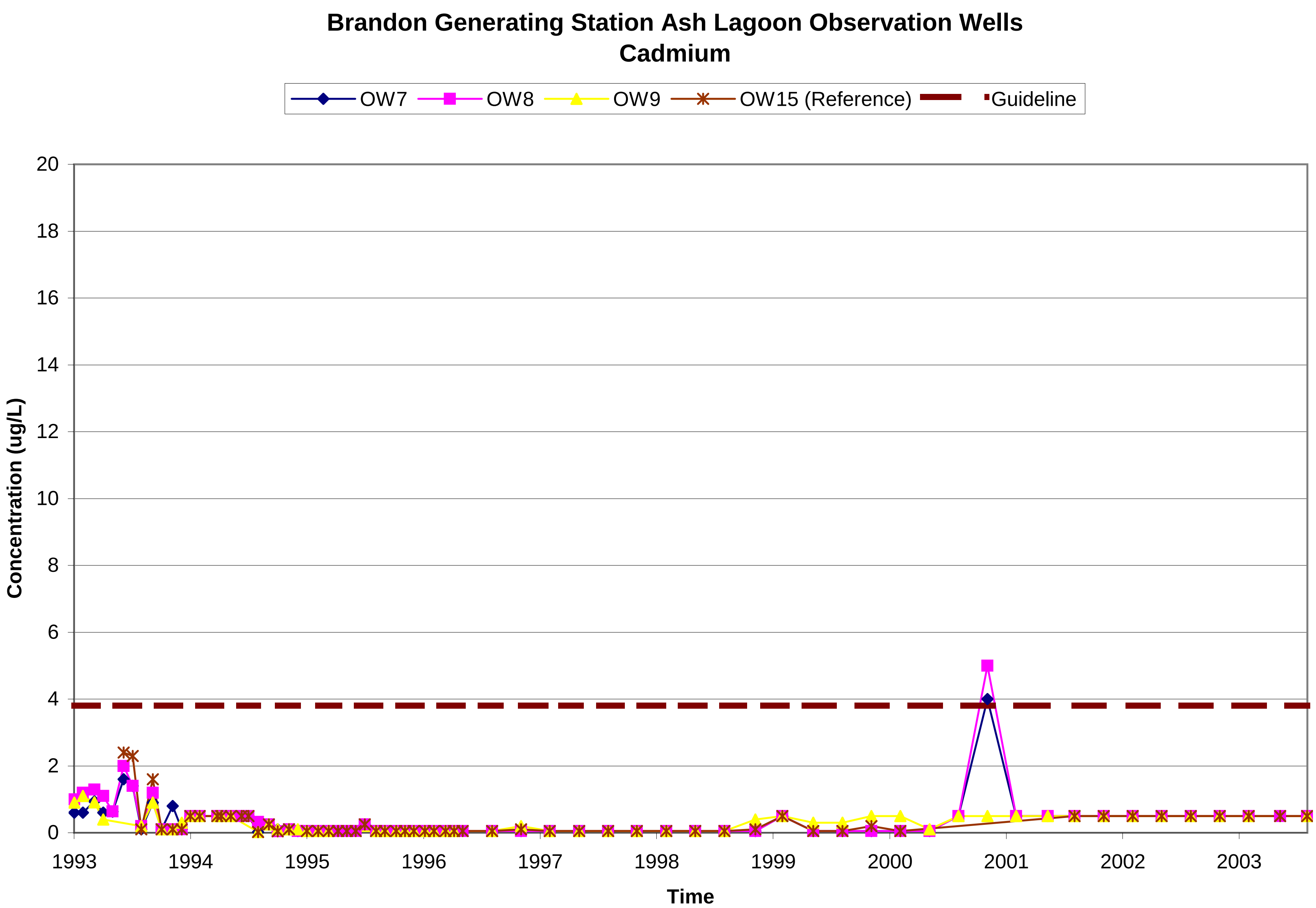
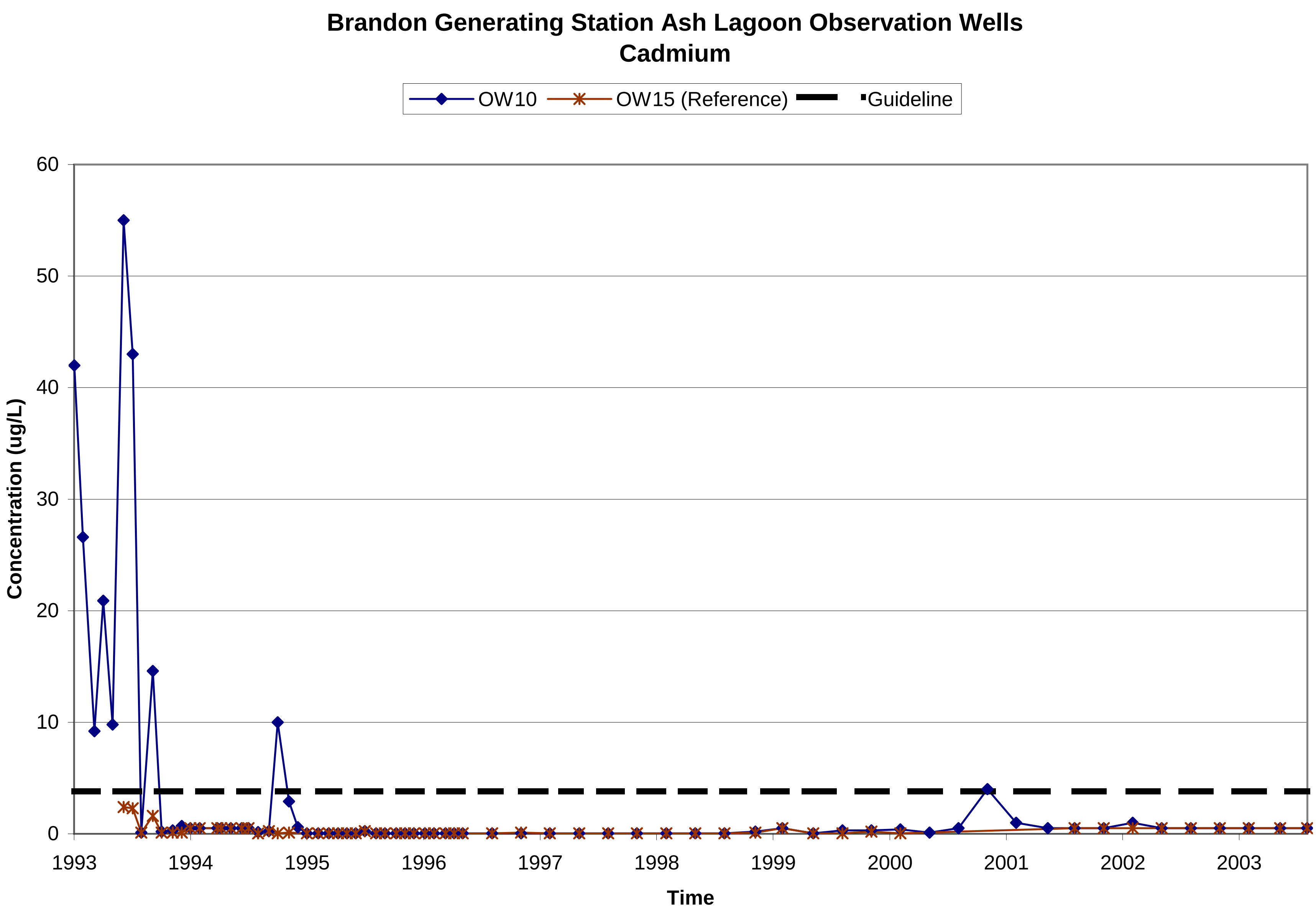

Brandon Generating Station Ash Lagoon Observation Wells
Cadmium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
0
2
4
6
8
10
12
14
16
18
20
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-24



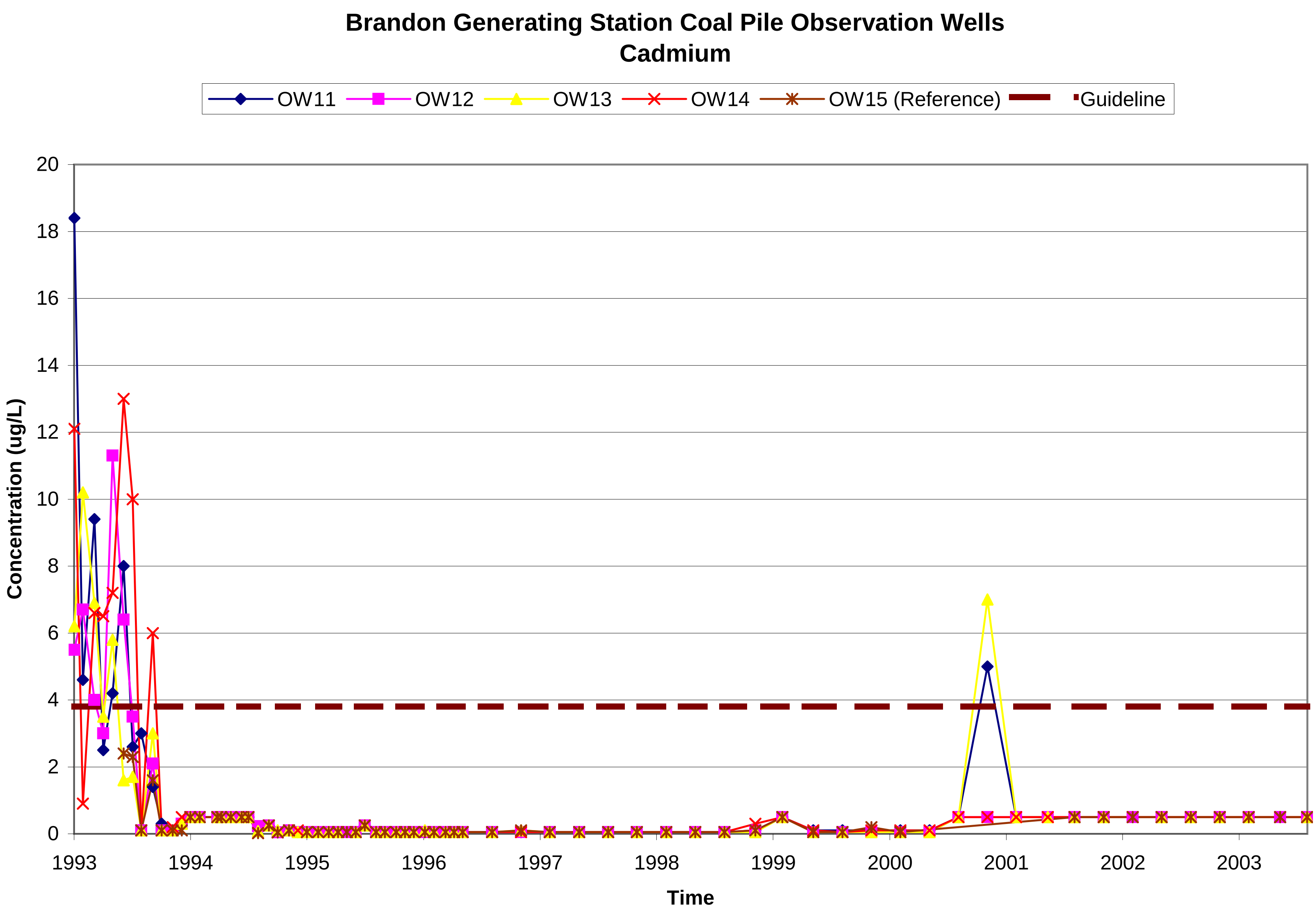
Brandon Generating Station Ash Lagoon Observation Wells
Cadmium
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (ug/L)
20
18
16
14
12
10
8
6
4
2
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-25



Brandon Generating Station Ash Lagoon Observation Wells
Cadmium
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-26



Brandon Generating Station Coal Pile Observation Wells
Cadmium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
0
2
4
6
8
10
12
14
16
18
20
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-27

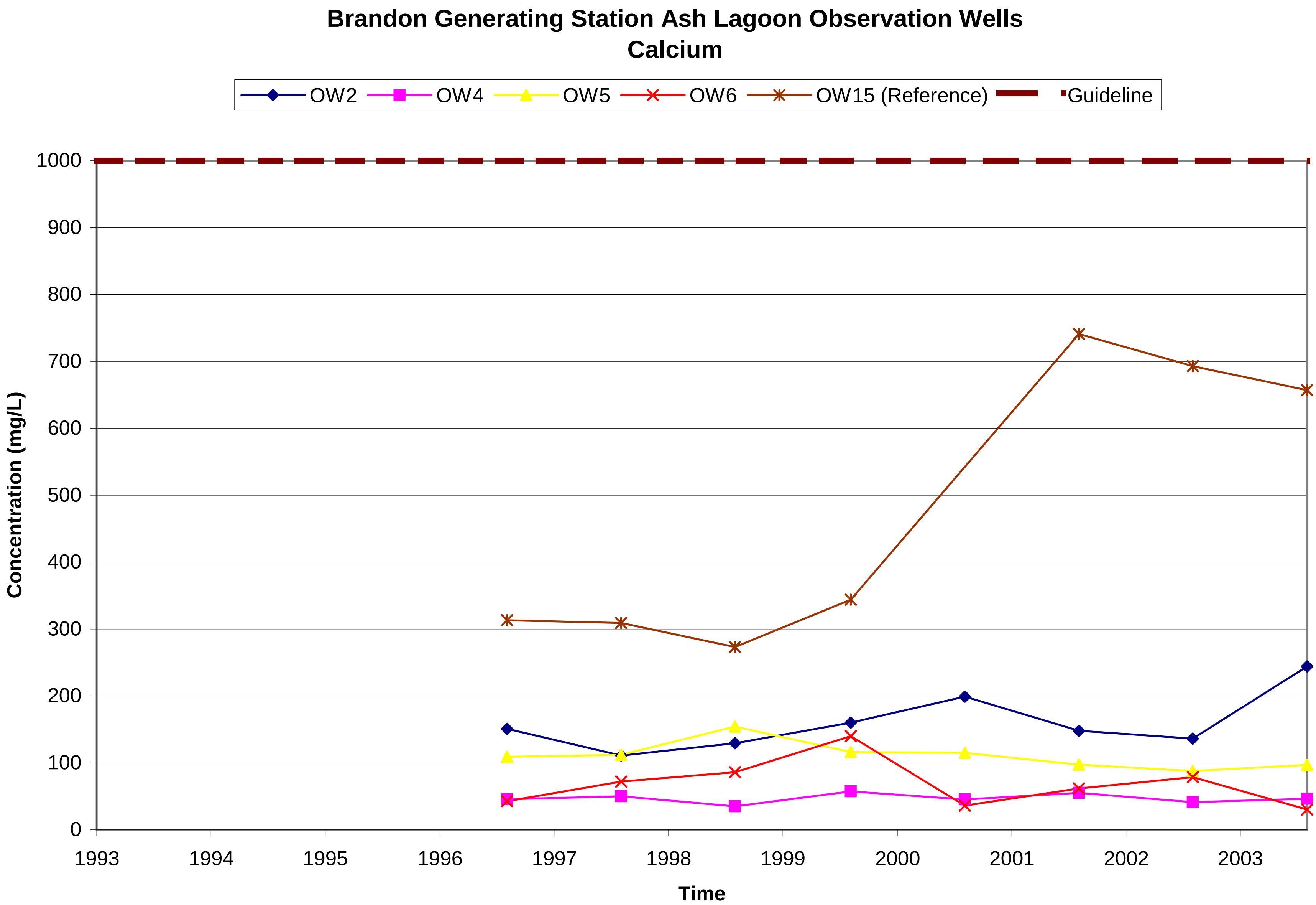
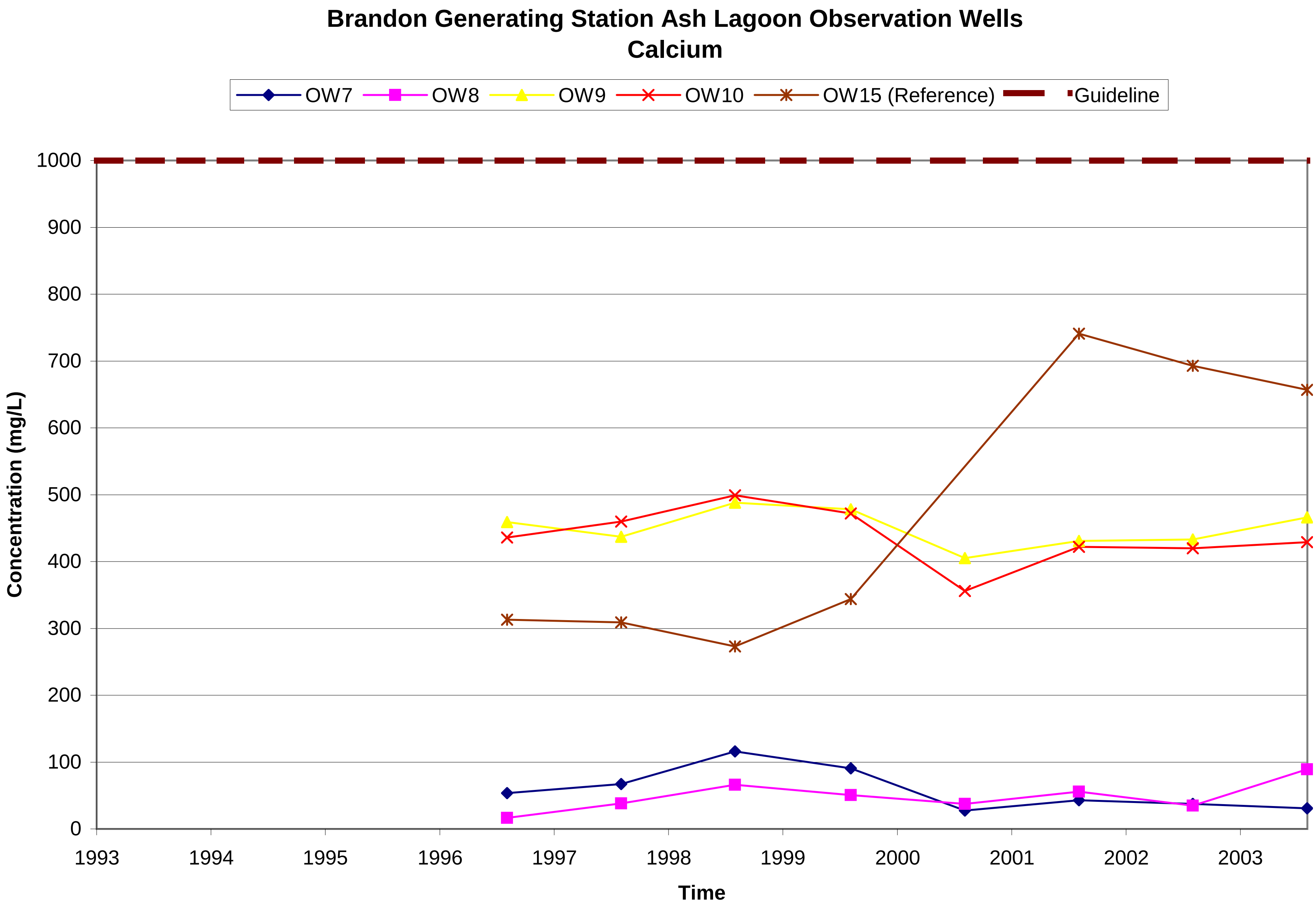

Brandon Generating Station Ash Lagoon Observation Wells
Calcium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-28



Brandon Generating Station Ash Lagoon Observation Wells
Calcium
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
1000
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-29

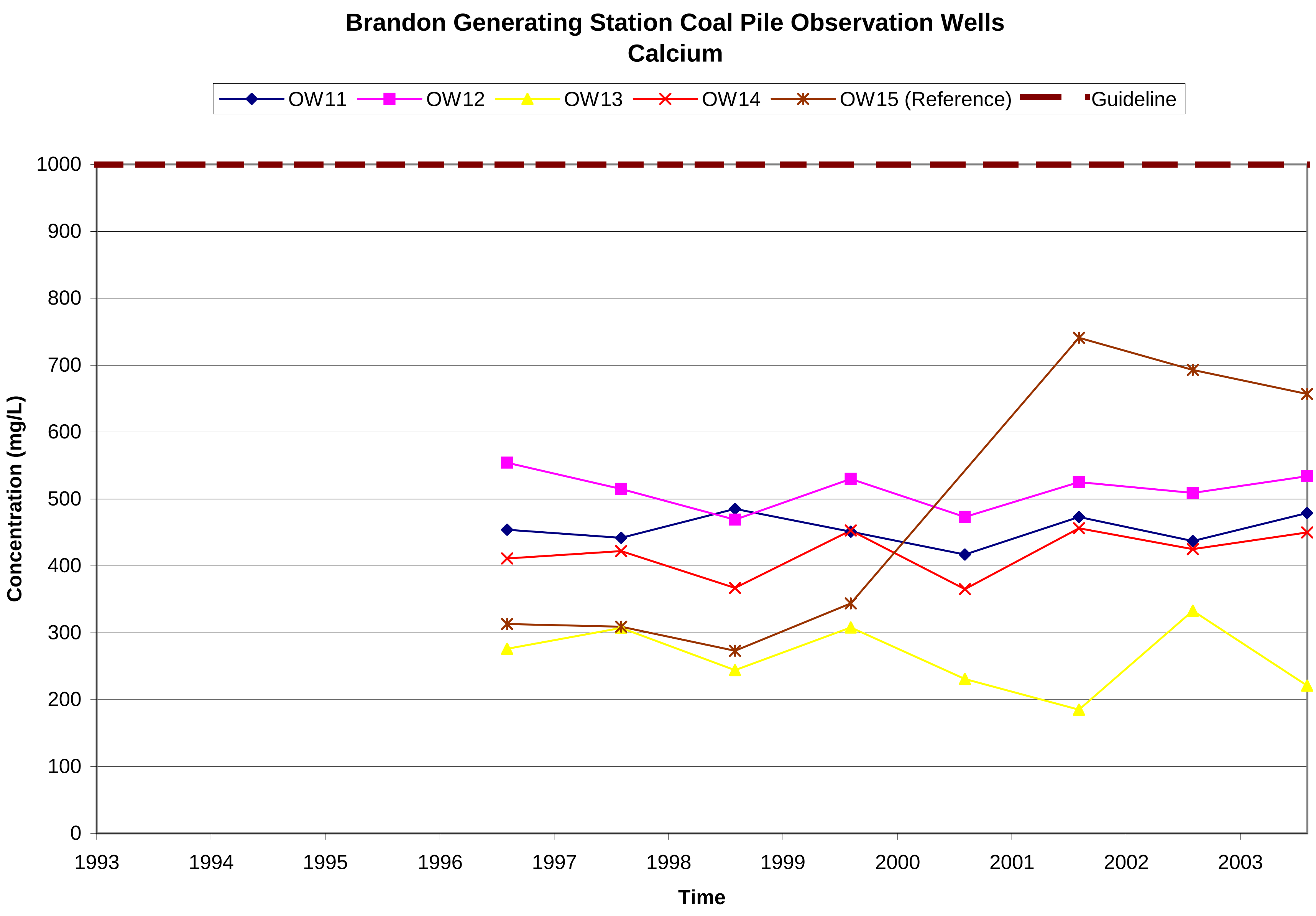
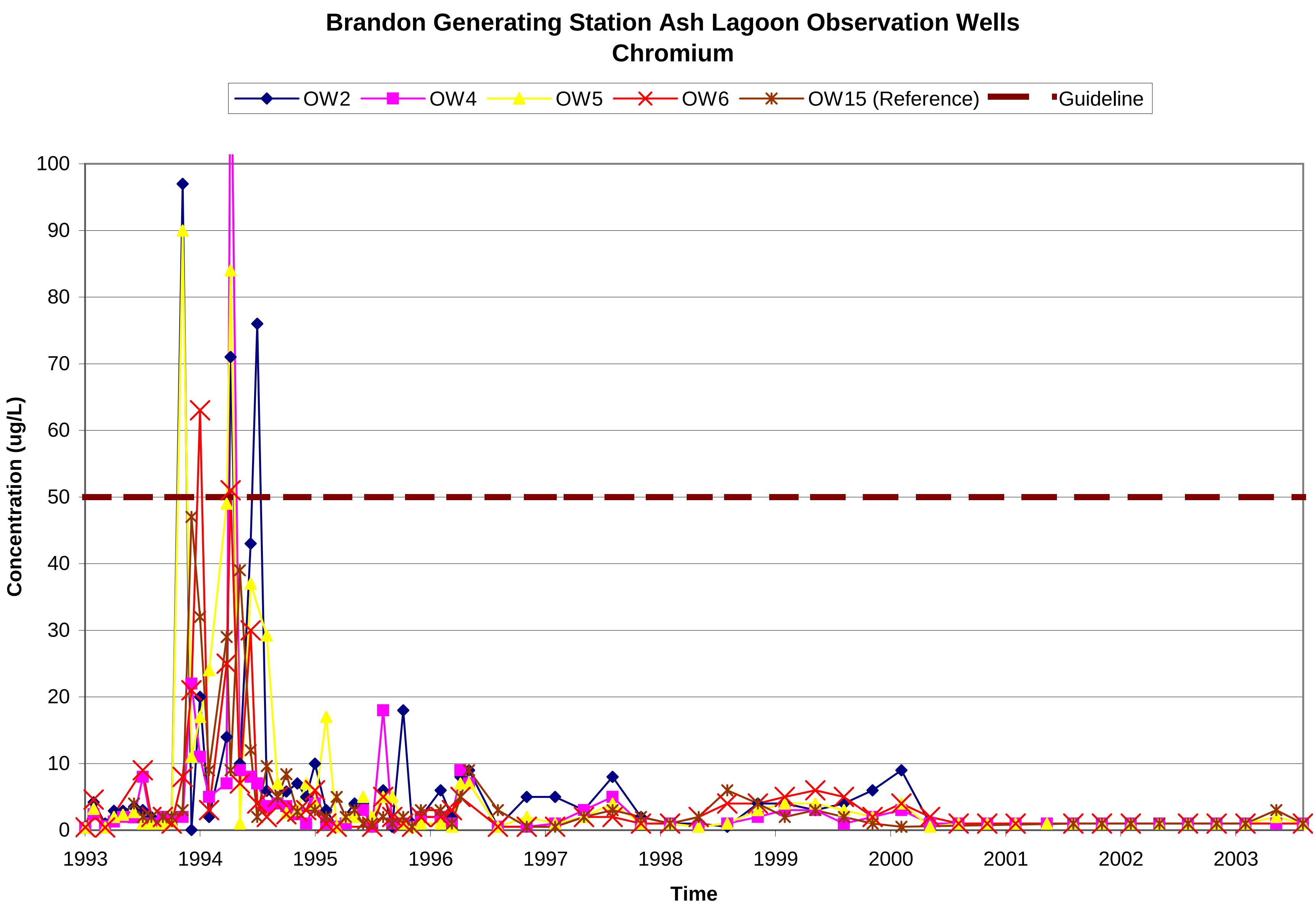

Brandon Generating Station Coal Pile Observation Wells
Calcium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-30



Brandon Generating Station Ash Lagoon Observation Wells
Chromium
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-31

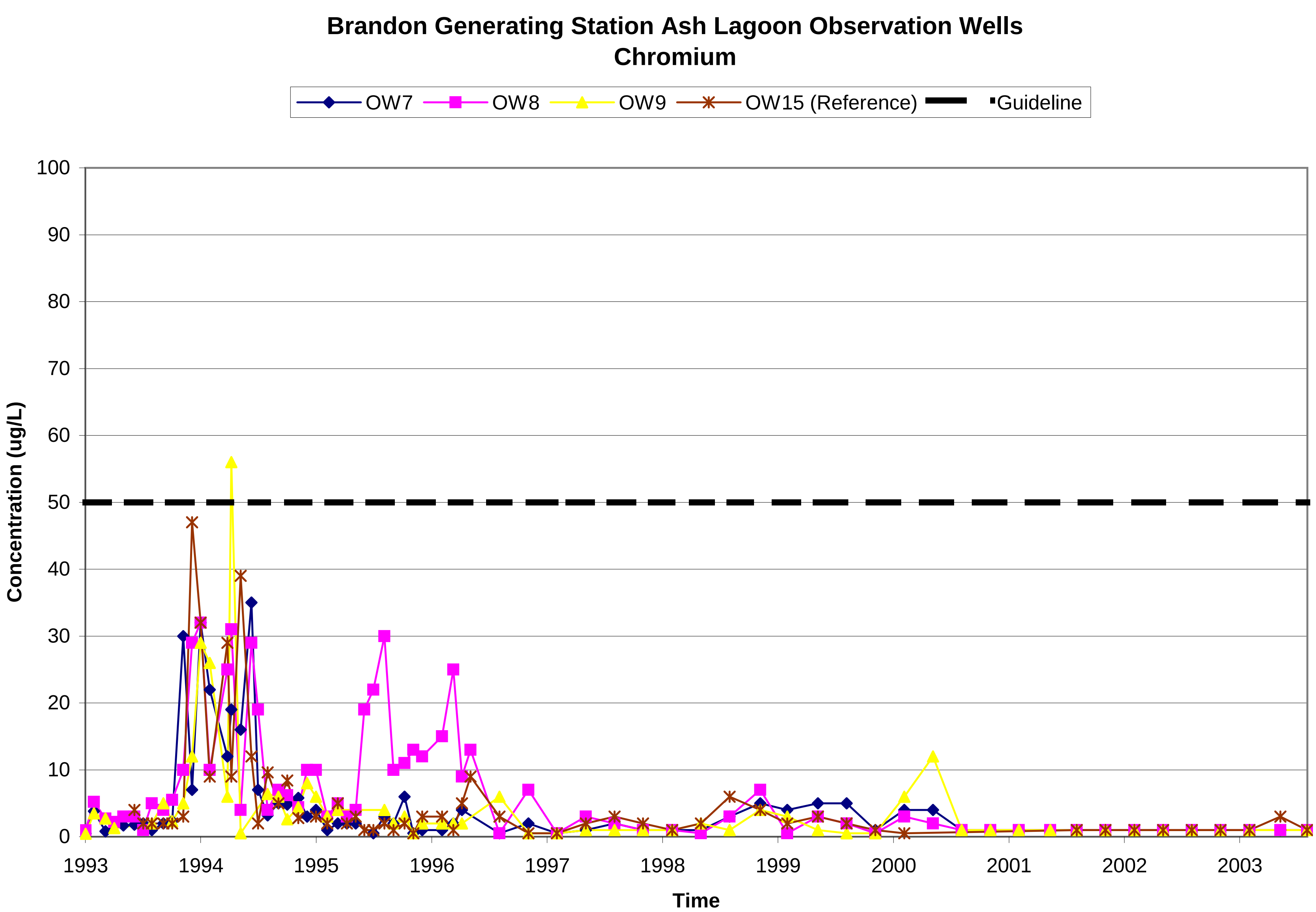
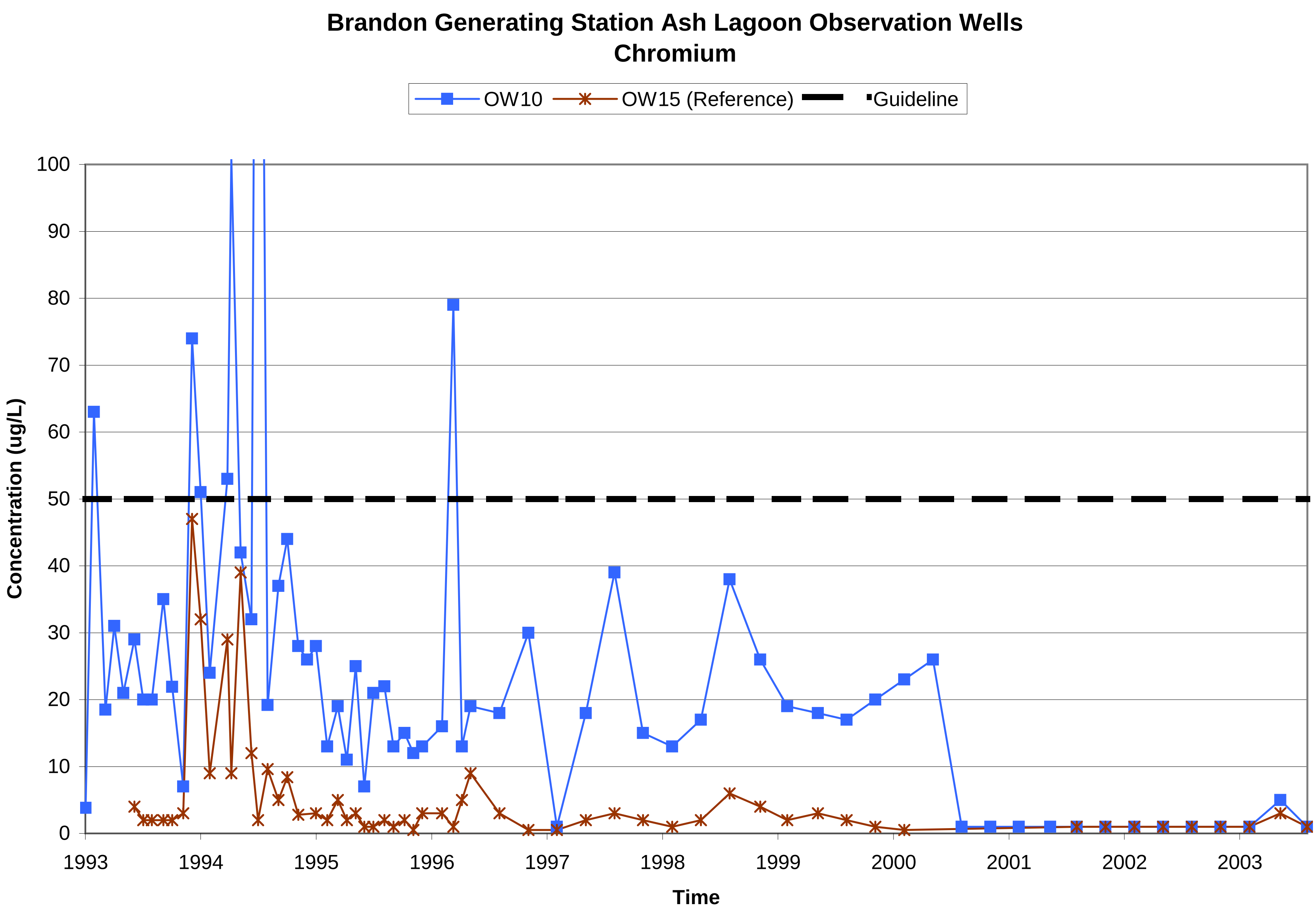
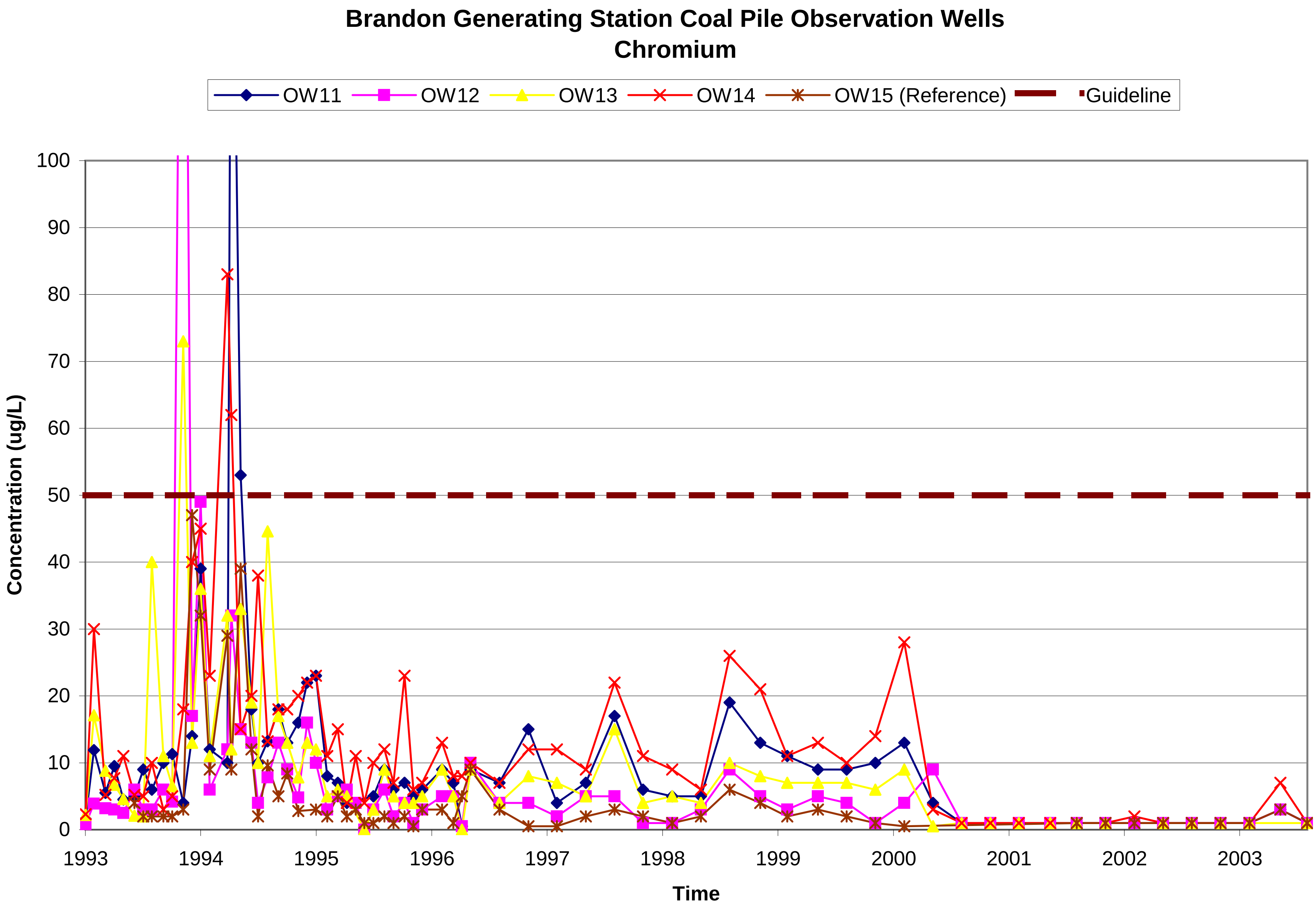

Brandon Generating Station Ash Lagoon Observation Wells
Chromium
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (ug/L)
0
10
20
30
40
50
60
70
80
90
100
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-32



Brandon Generating Station Ash Lagoon Observation Wells
Chromium
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-33



Brandon Generating Station Coal Pile Observation Wells
Chromium
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-34

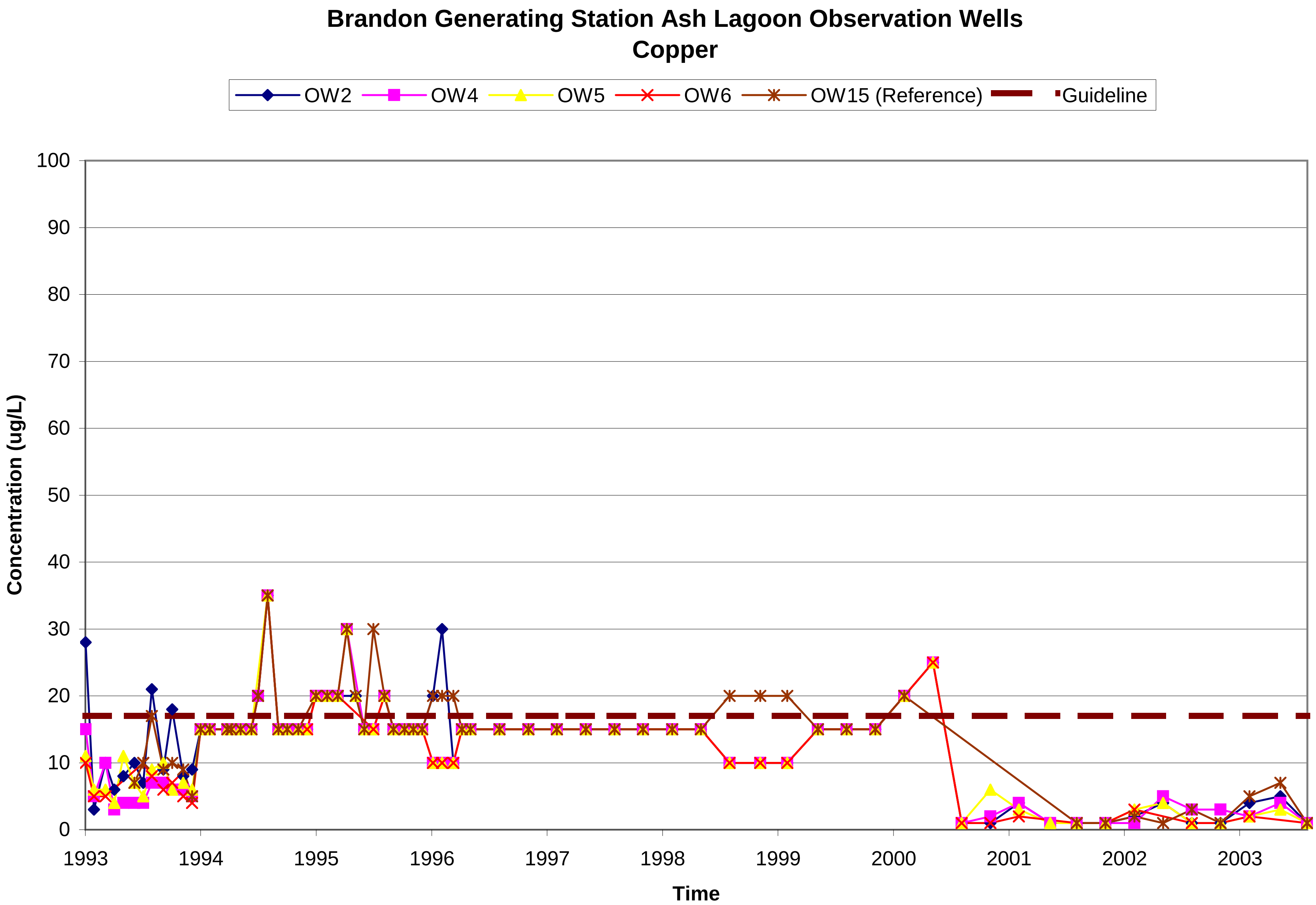

Brandon Generating Station Ash Lagoon Observation Wells
Copper
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-35

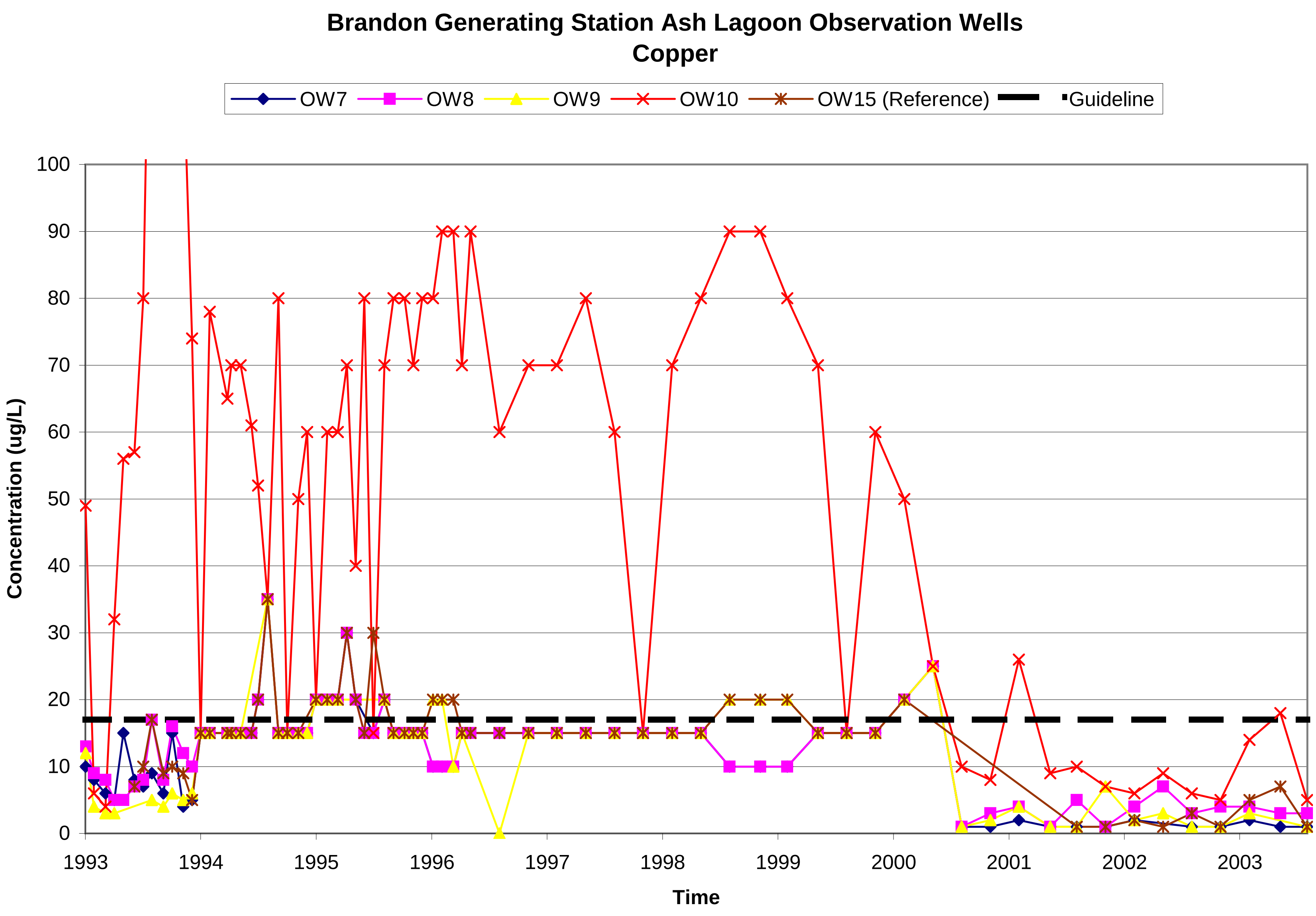

Brandon Generating Station Ash Lagoon Observation Wells
Copper
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
100
90
80
70
60
50
40
30
20
10
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-36

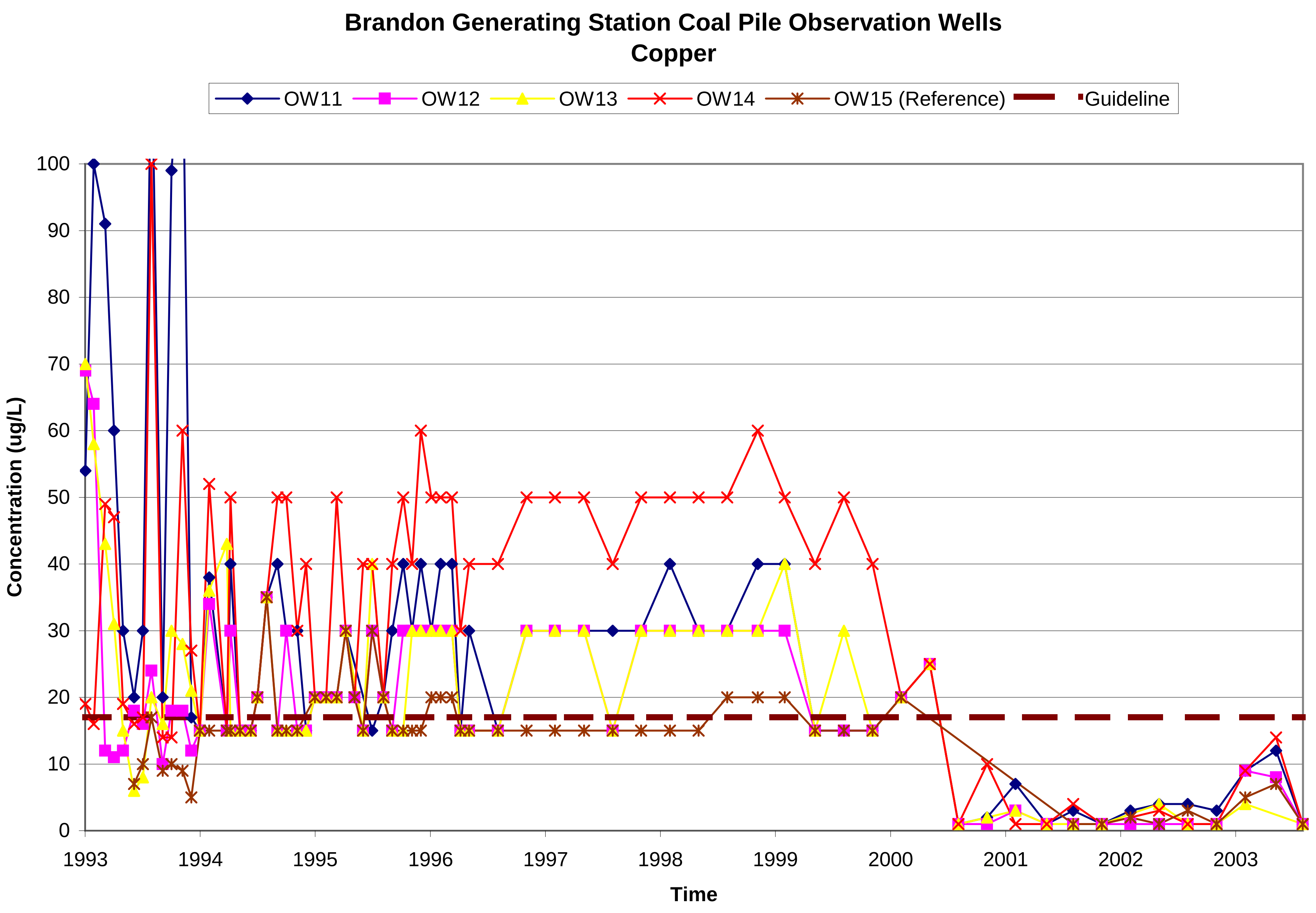
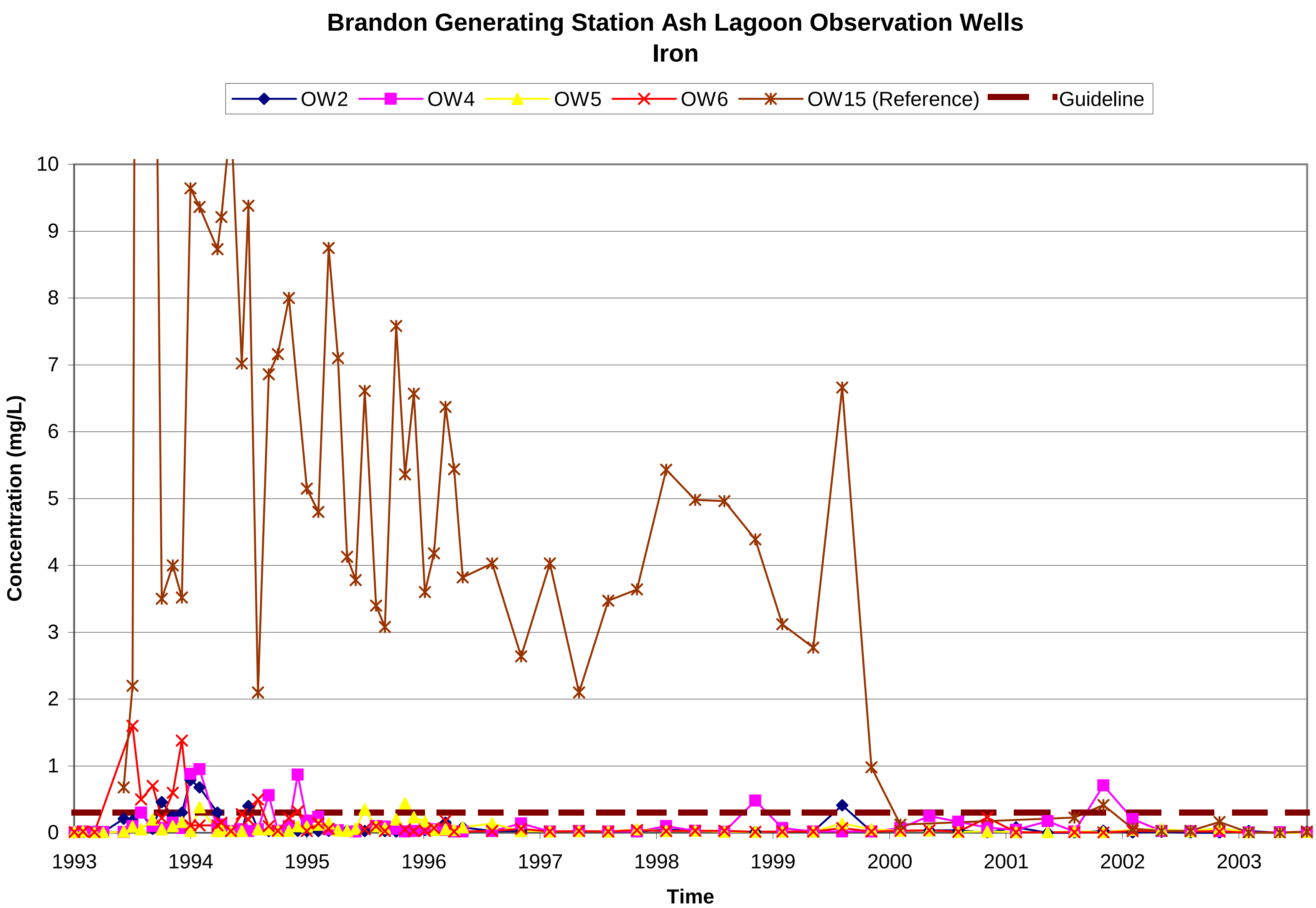
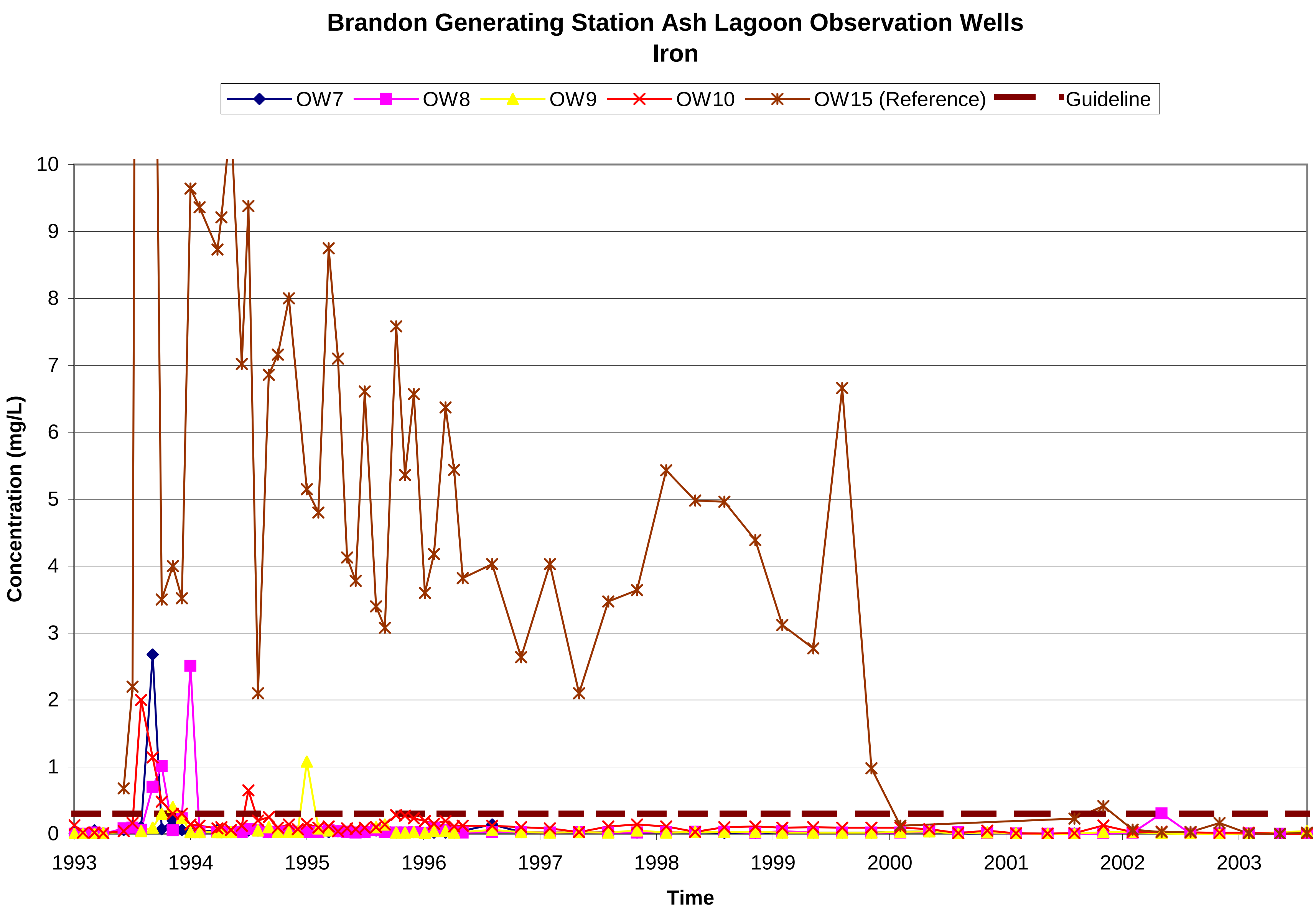

Brandon Generating Station Coal Pile Observation Wells
Copper
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
0
10
20
30
40
50
60
70
80
90
100
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-37



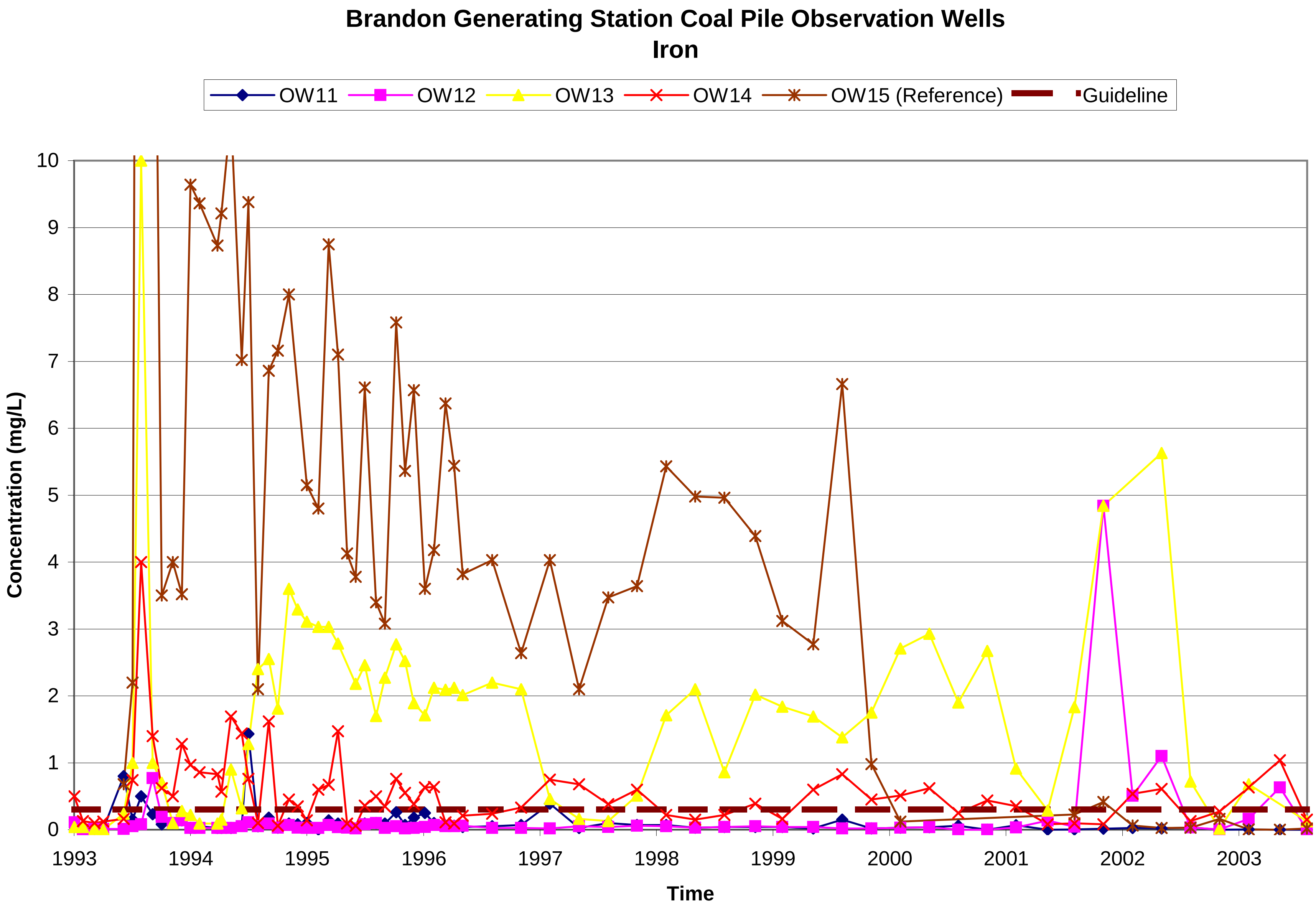
Brandon Generating Station Ash Lagoon Observation Wells
Iron
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-38



Brandon Generating Station Ash Lagoon Observation Wells
Iron
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-39



Brandon Generating Station Coal Pile Observation Wells
Iron
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-40

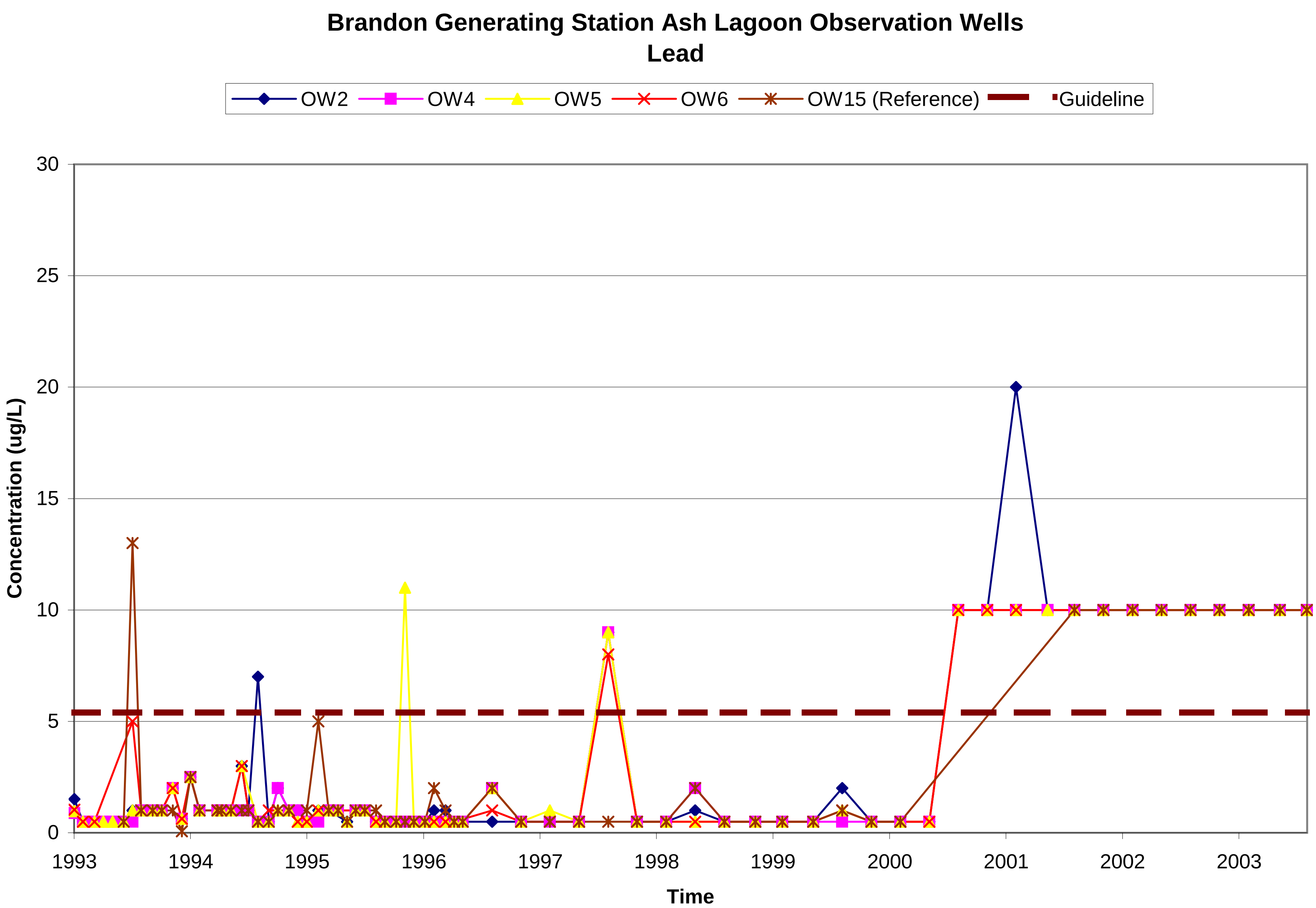

Brandon Generating Station Ash Lagoon Observation Wells
Lead
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
0
5
10
15
20
25
30
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-41

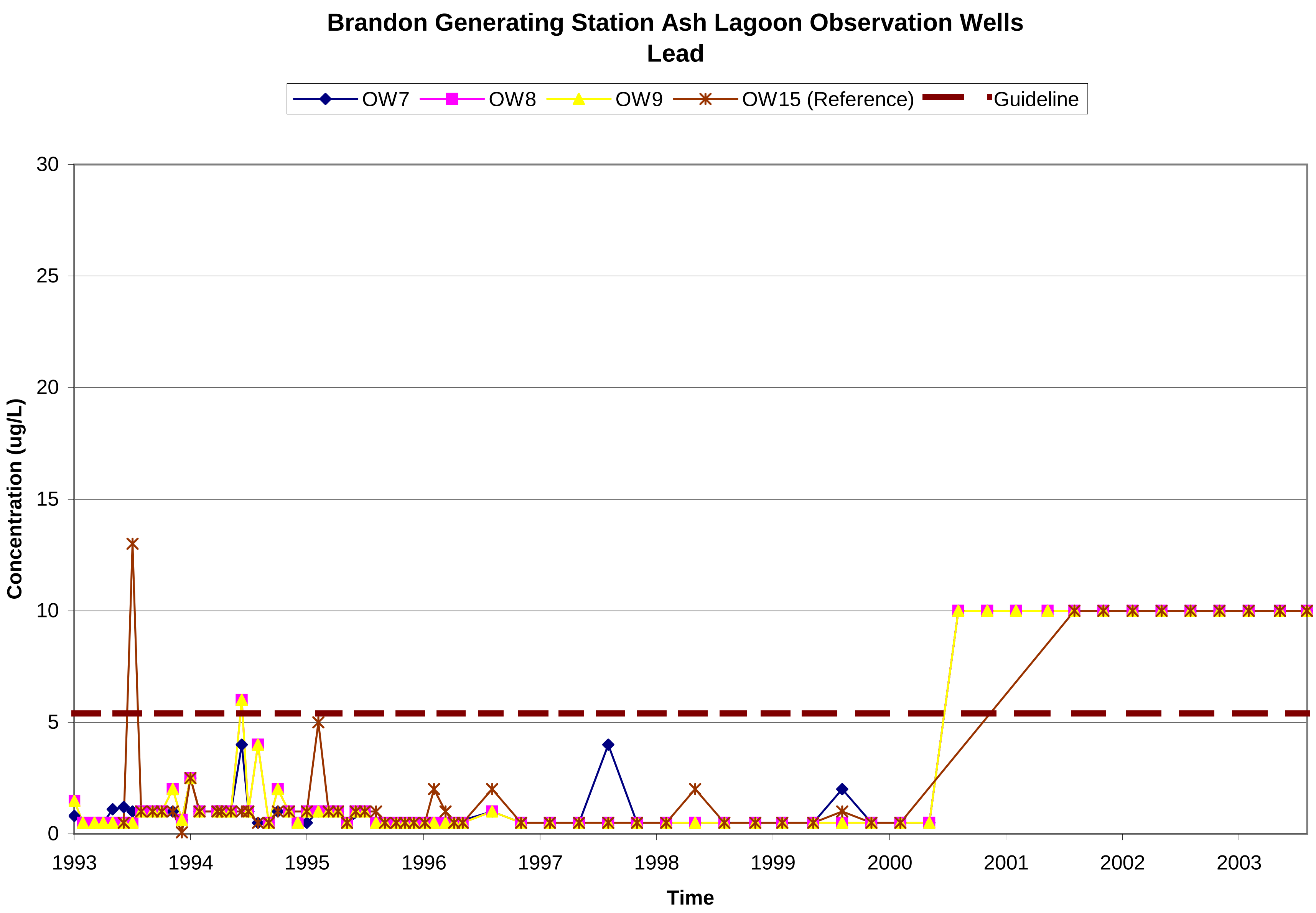

Brandon Generating Station Ash Lagoon Observation Wells
Lead
OW7
OW8
OW9
OW15 (Reference)
Guideline
Concentration (ug/L)
0
5
10
15
20
25
30
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-42

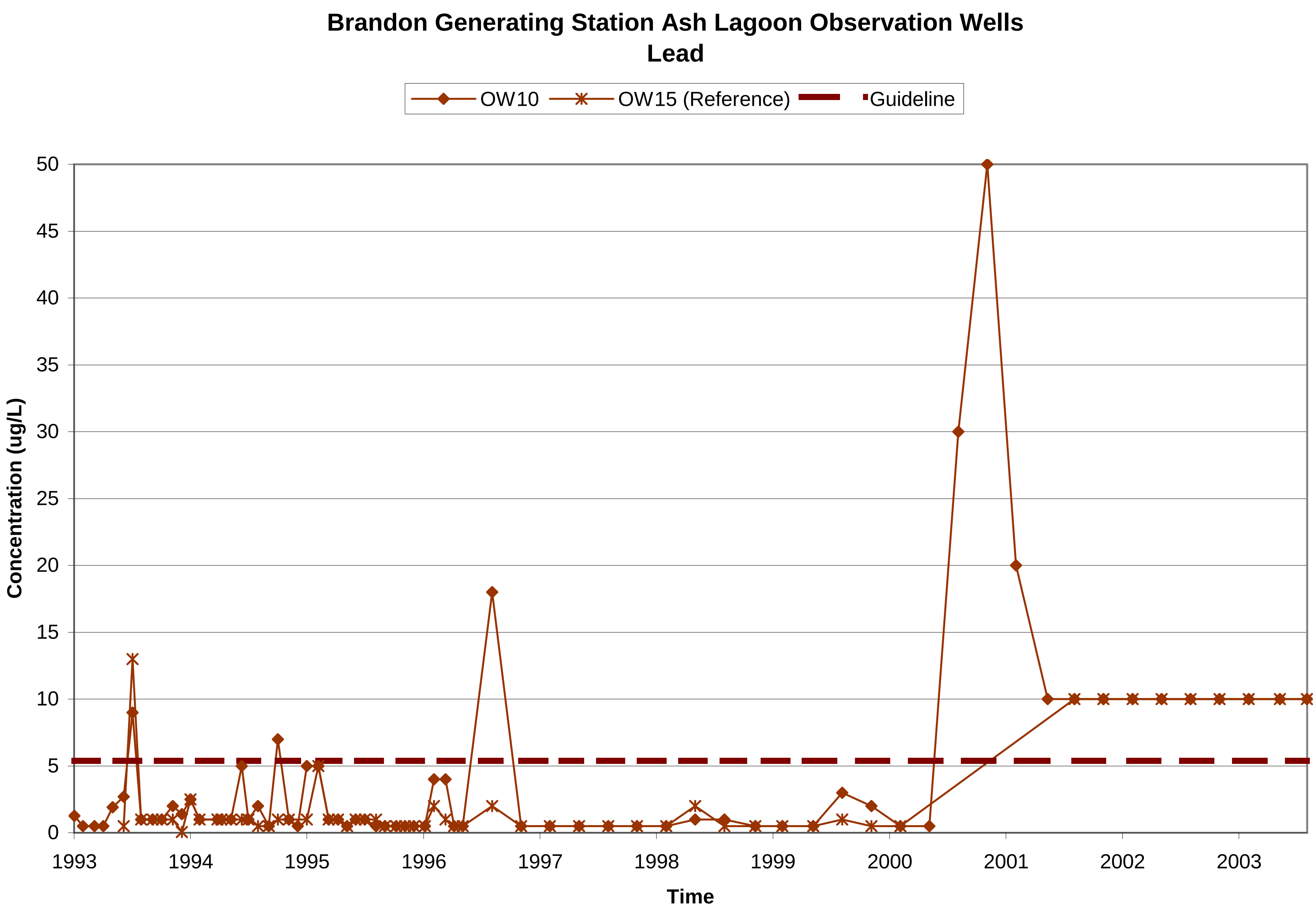
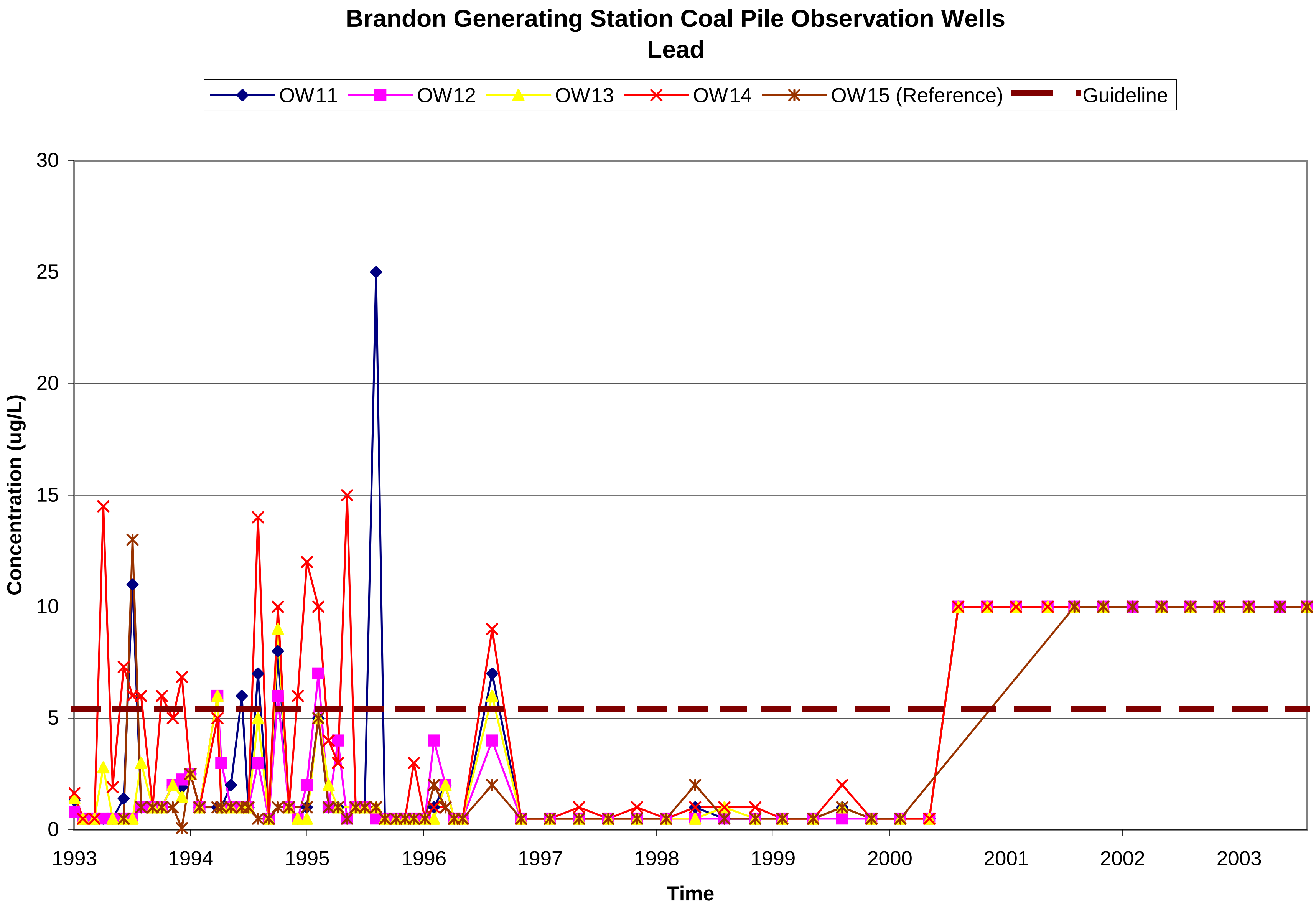

Brandon Generating Station Ash Lagoon Observation Wells
Lead
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
50
45
40
35
30
25
20
15
10
5
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-43



Brandon Generating Station Coal Pile Observation Wells
Lead
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
30
25
20
15
10
5
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-44

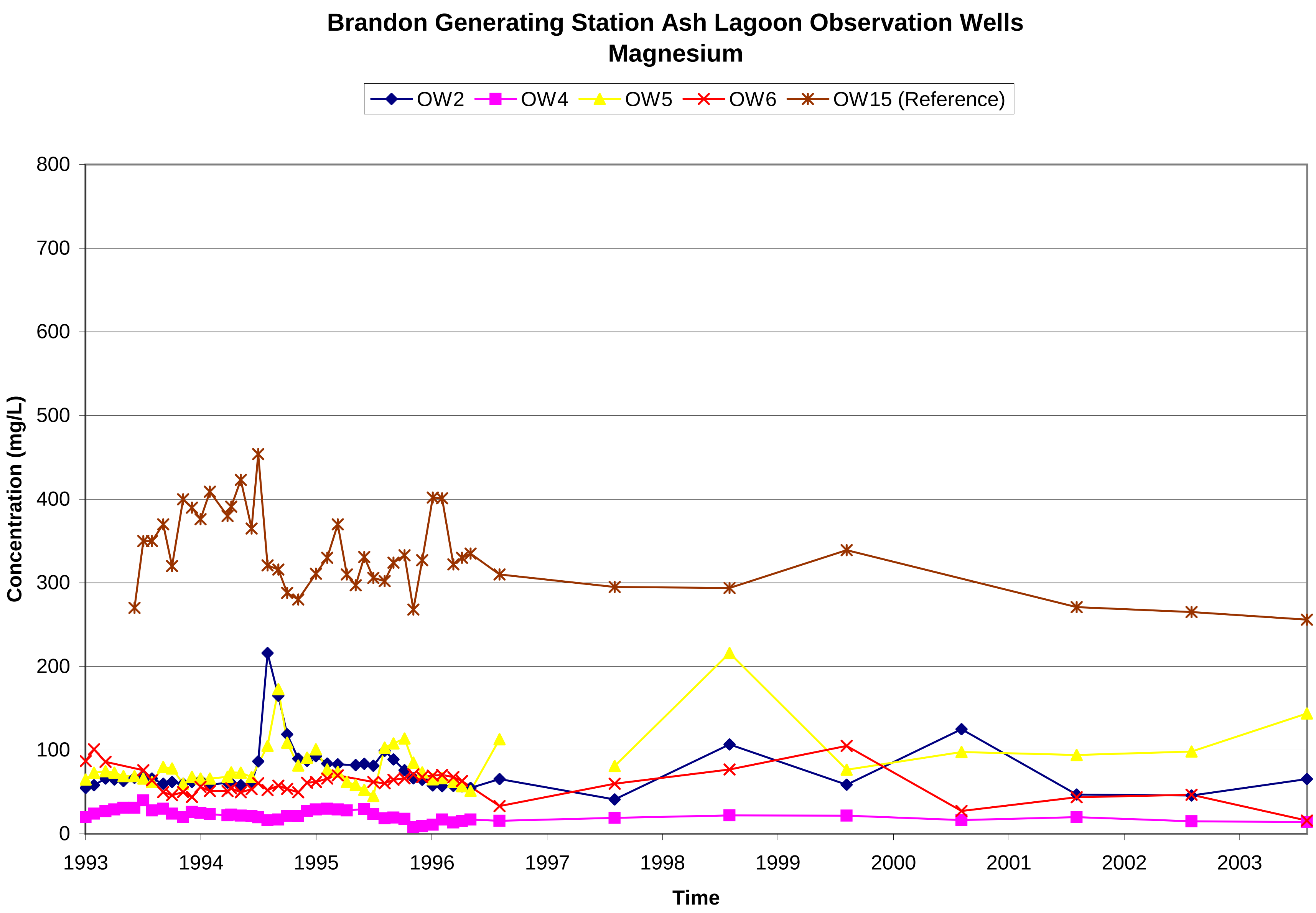

Brandon Generating Station Ash Lagoon Observation Wells
Magnesium
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg/L)
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-45

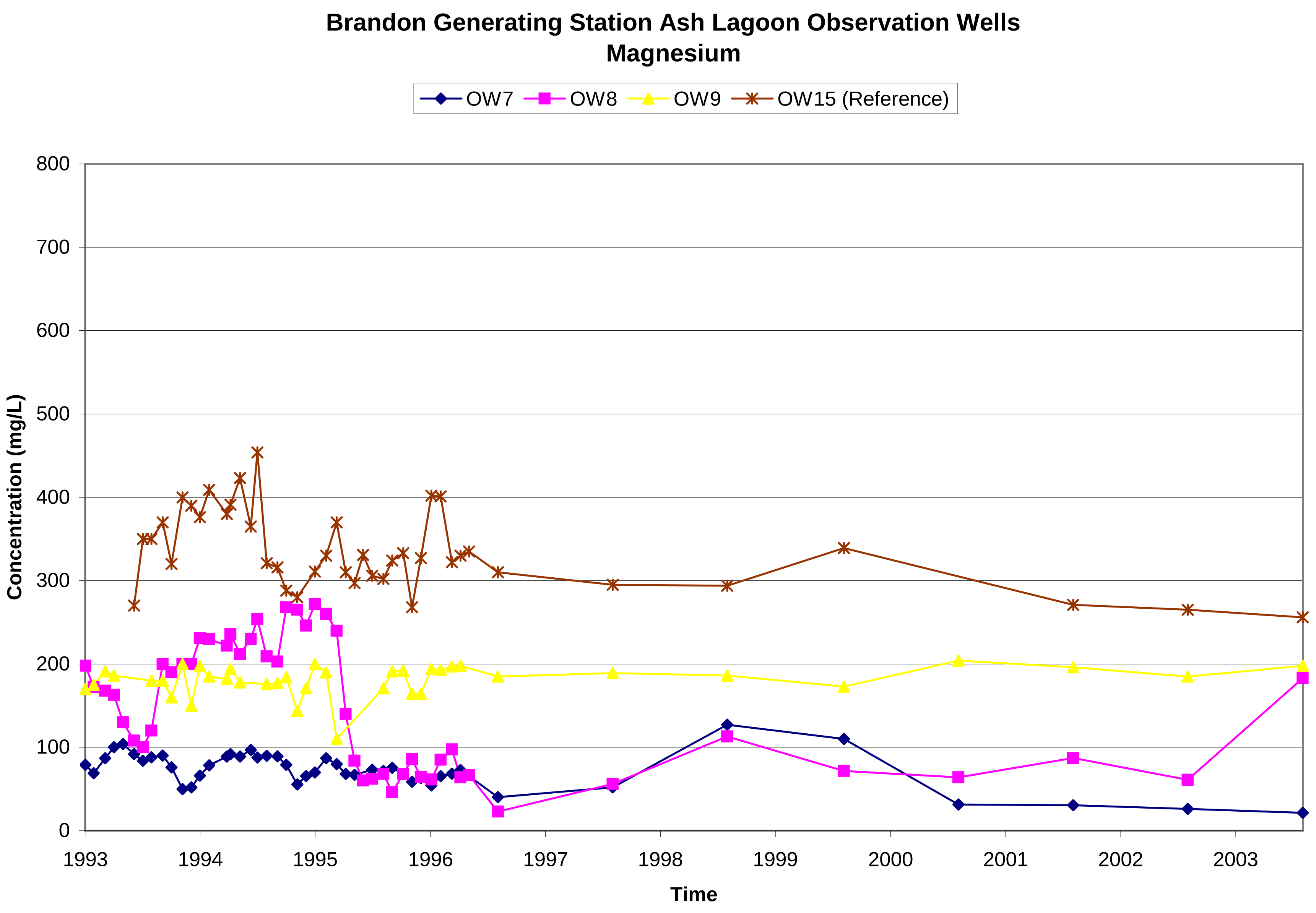

Brandon Generating Station Ash Lagoon Observation Wells
Magnesium
OW7
OW8
OW9
OW15 (Reference)
Concentration (mg/L)
800
700
600
500
400
300
200
100
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-46

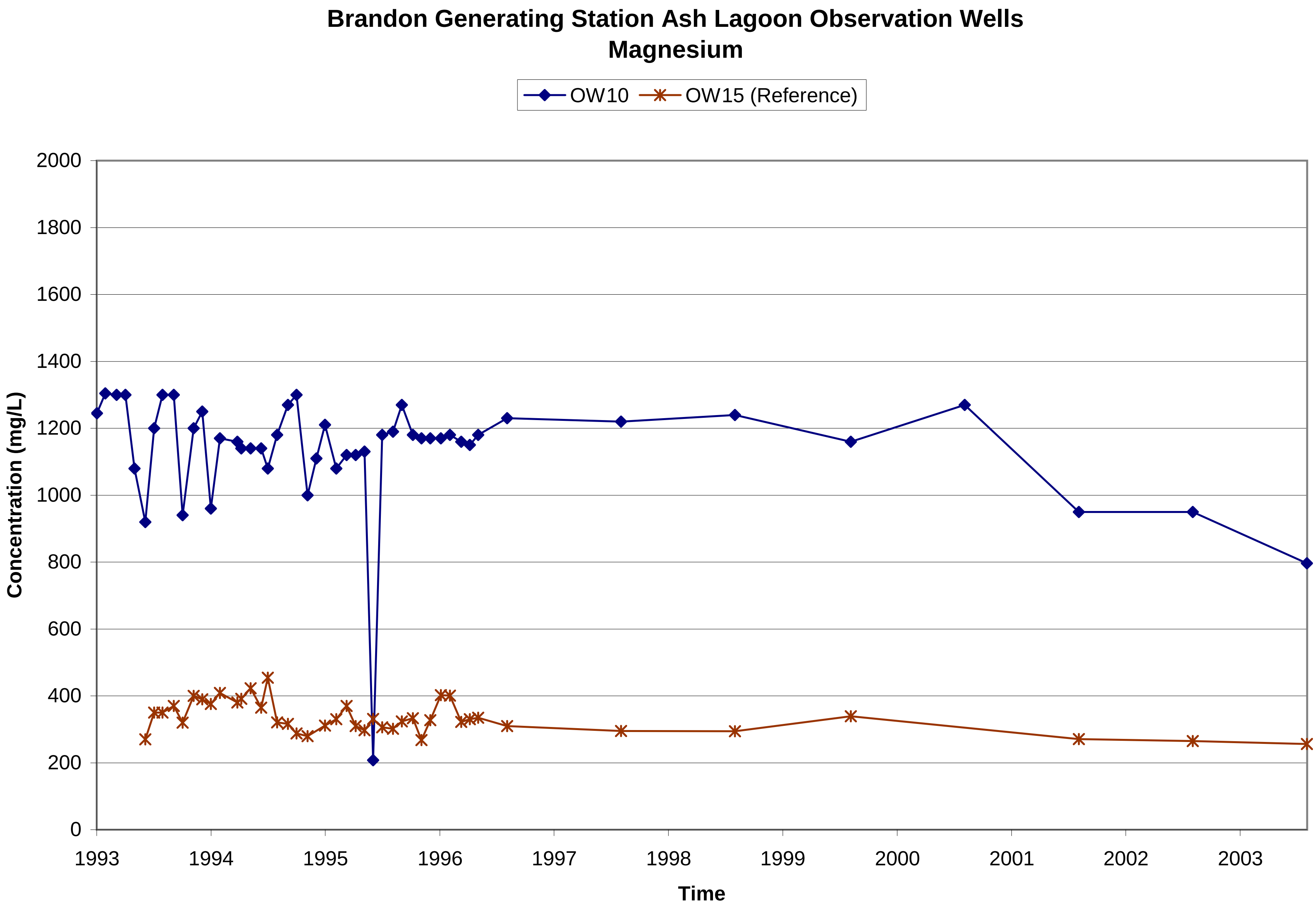
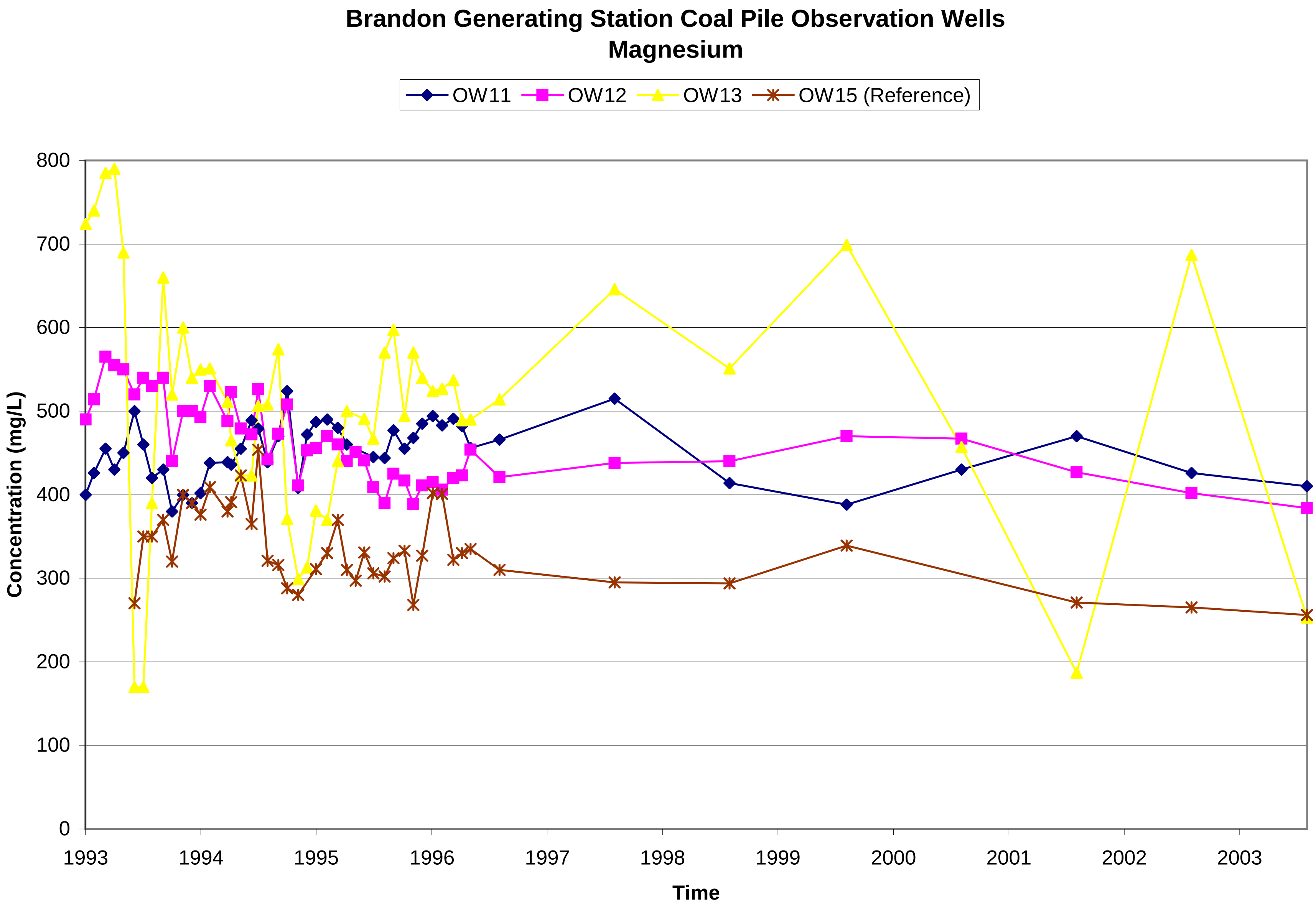
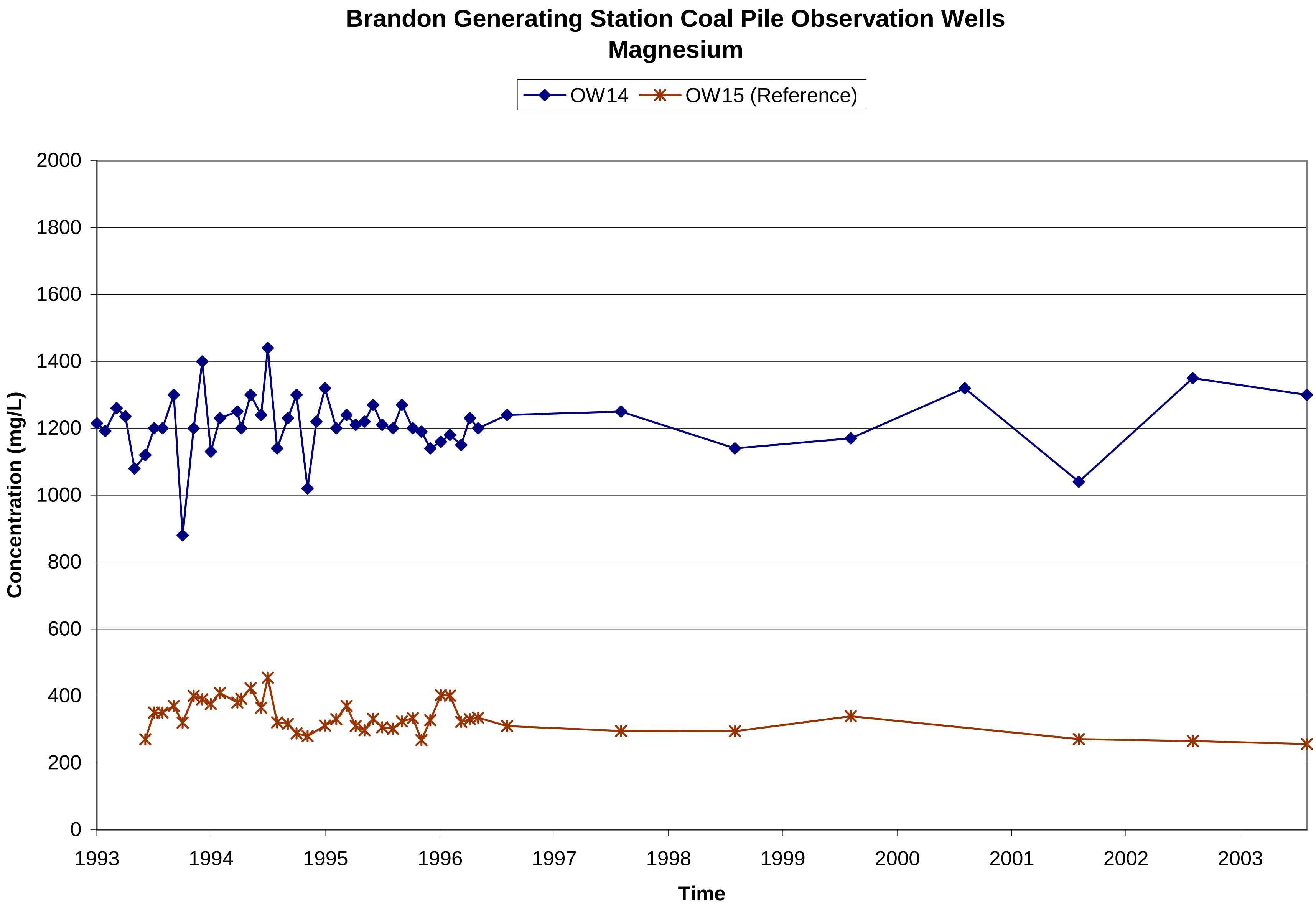

Brandon Generating Station Ash Lagoon Observation Wells
Magnesium
OW10
OW15 (Reference)
Concentration (mg/L)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-47



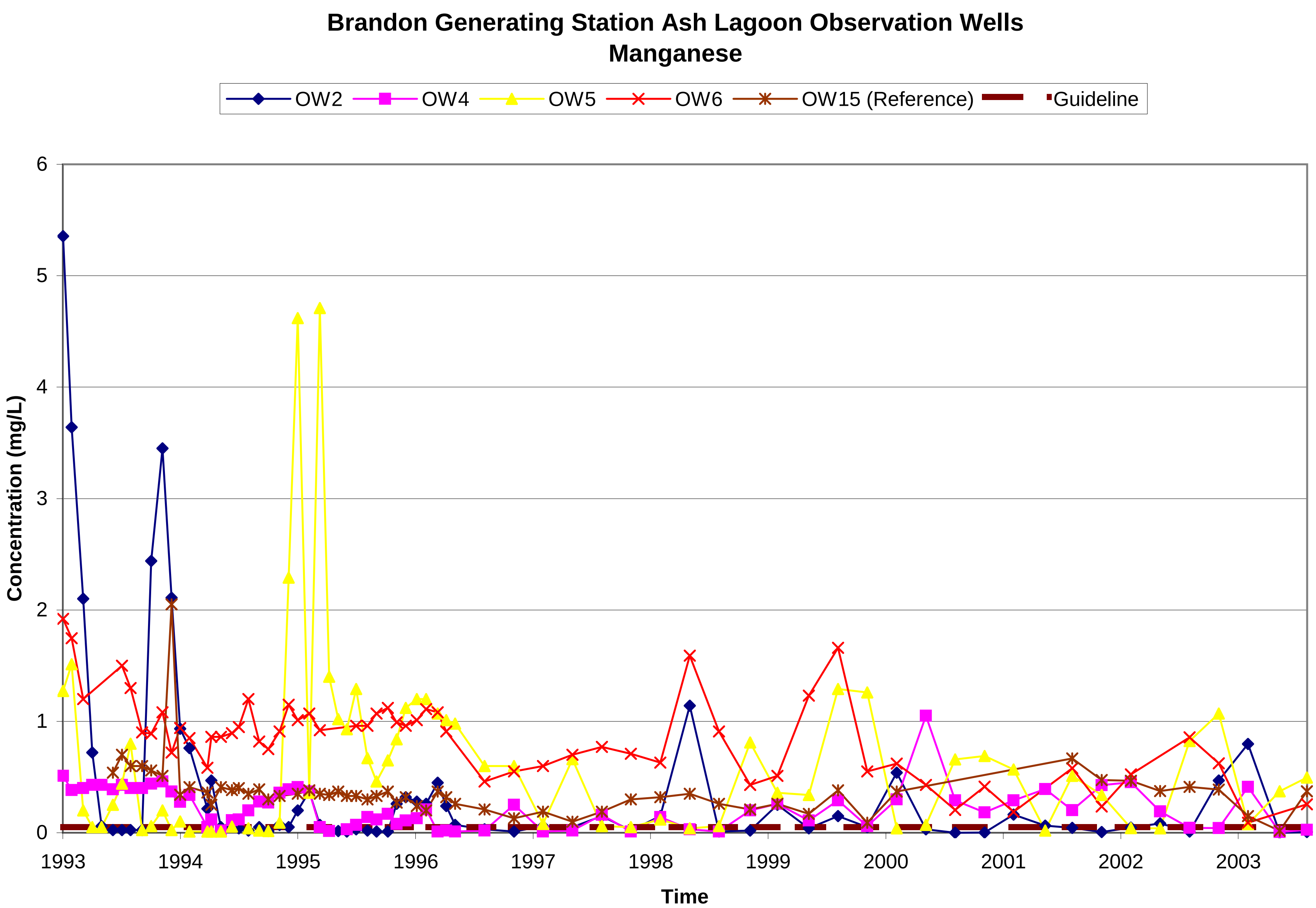
Brandon Generating Station Coal Pile Observation Wells
Magnesium
OW11
OW12
OW13
OW15 (Reference)
Concentration (mg/L)
0
100
200
300
400
500
600
700
800
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-48



Brandon Generating Station Coal Pile Observation Wells
Magnesium
OW14
OW15 (Reference)
Concentration (mg/L)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-49



Brandon Generating Station Ash Lagoon Observation Wells
Manganese
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-50

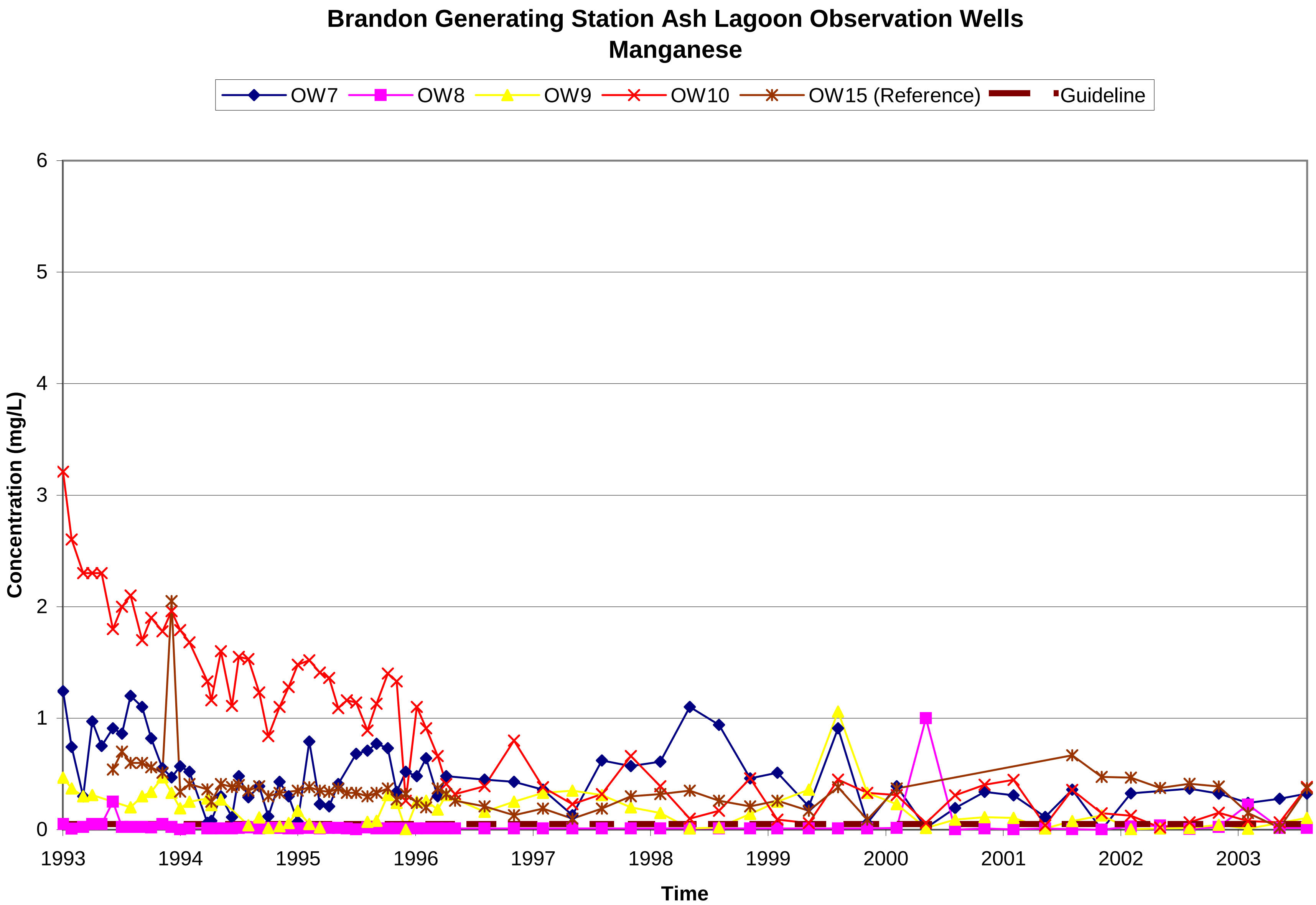

Brandon Generating Station Ash Lagoon Observation Wells
Manganese
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-51

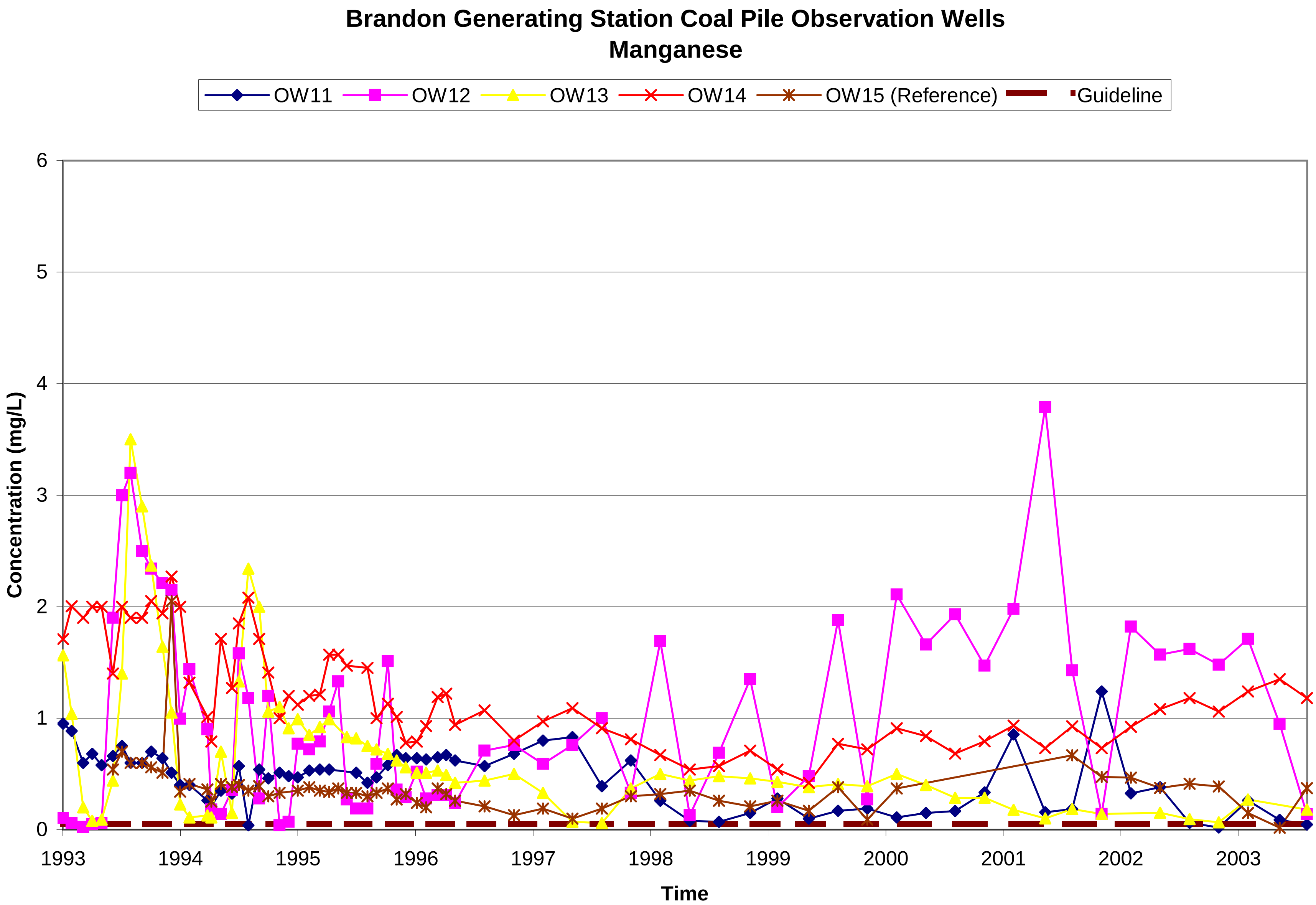

Brandon Generating Station Coal Pile Observation Wells
Manganese
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
0
1
2
3
4
5
6
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-52

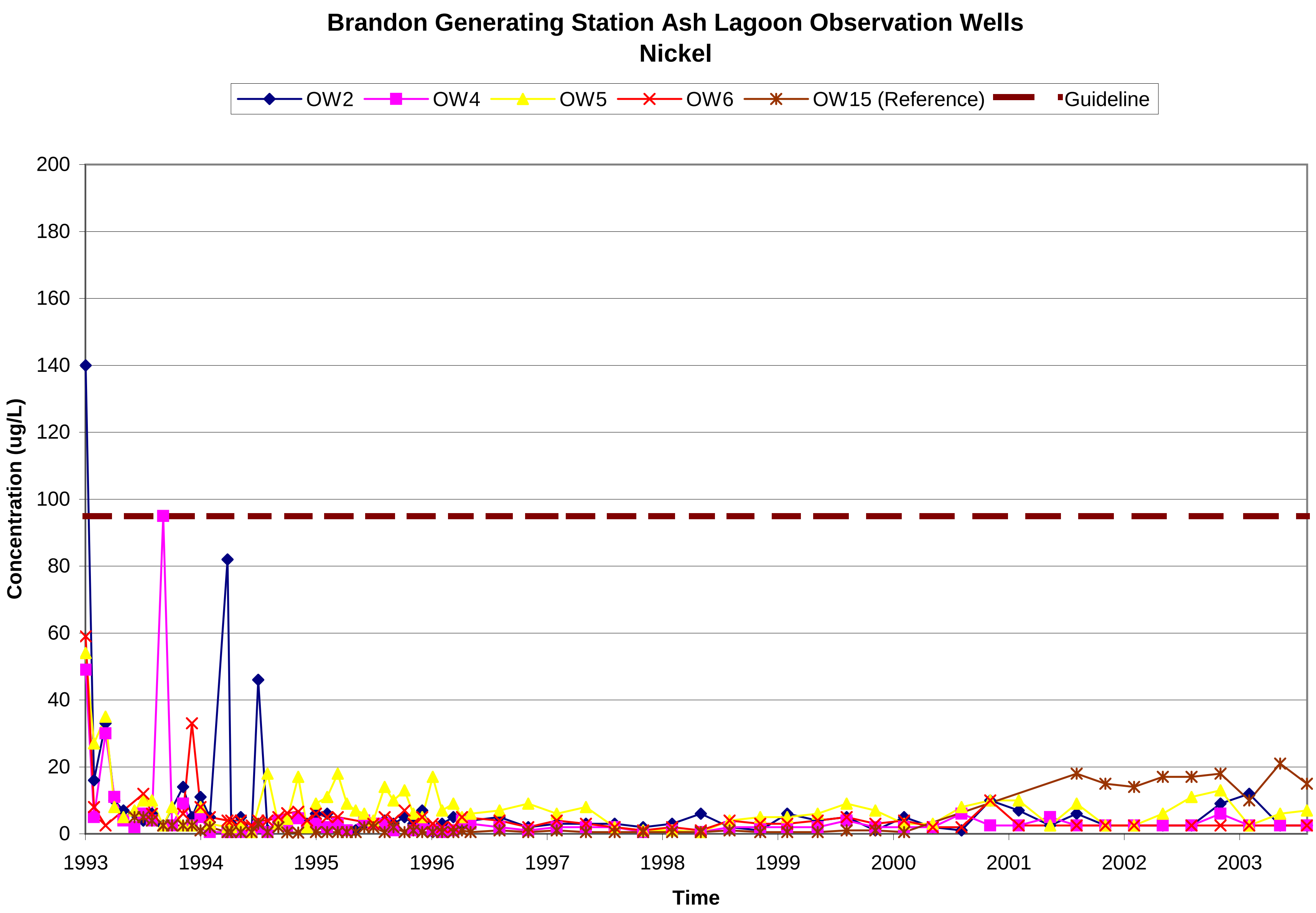
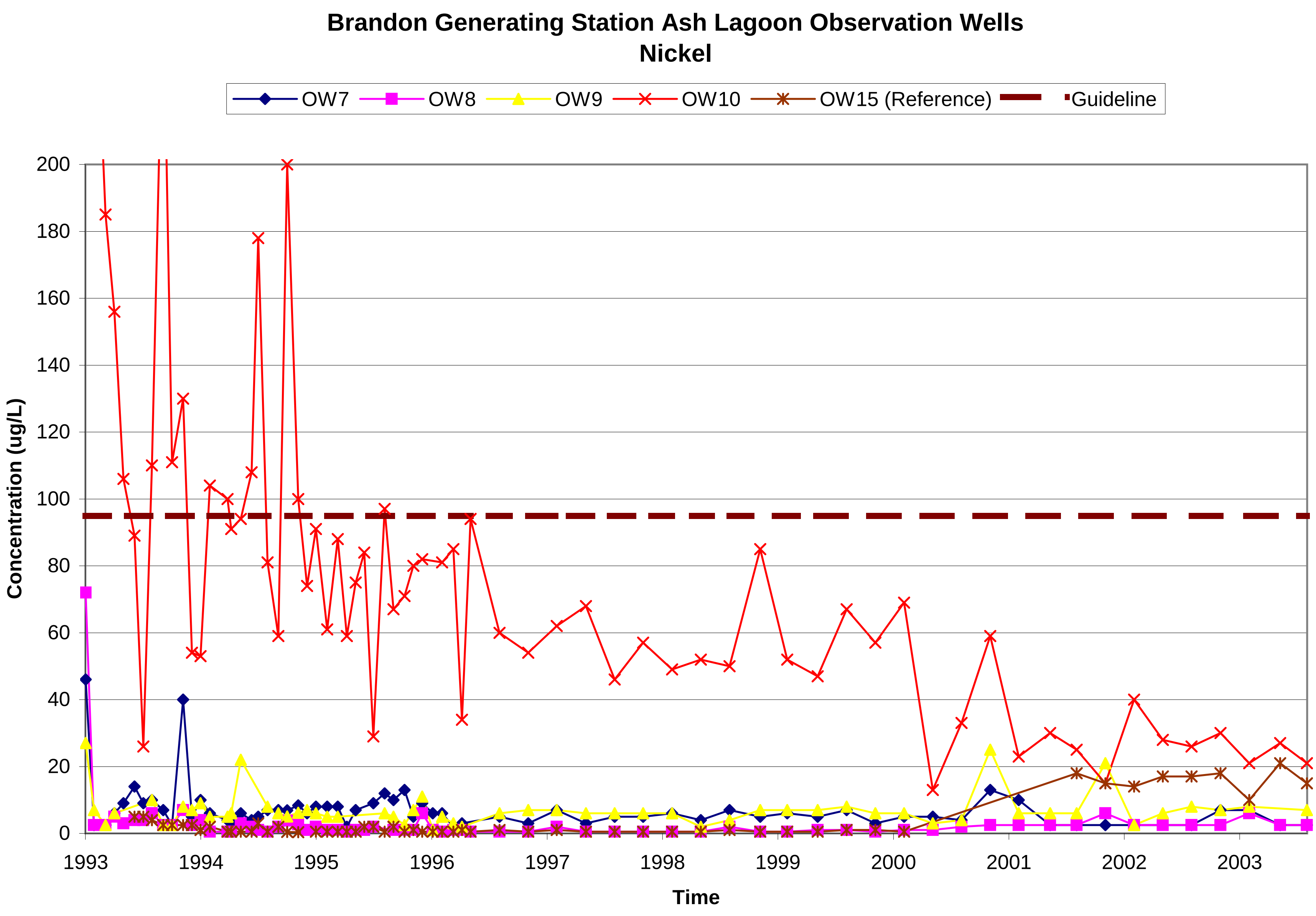

Brandon Generating Station Ash Lagoon Observation Wells
Nickel
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-53



Brandon Generating Station Ash Lagoon Observation Wells
Nickel
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-54

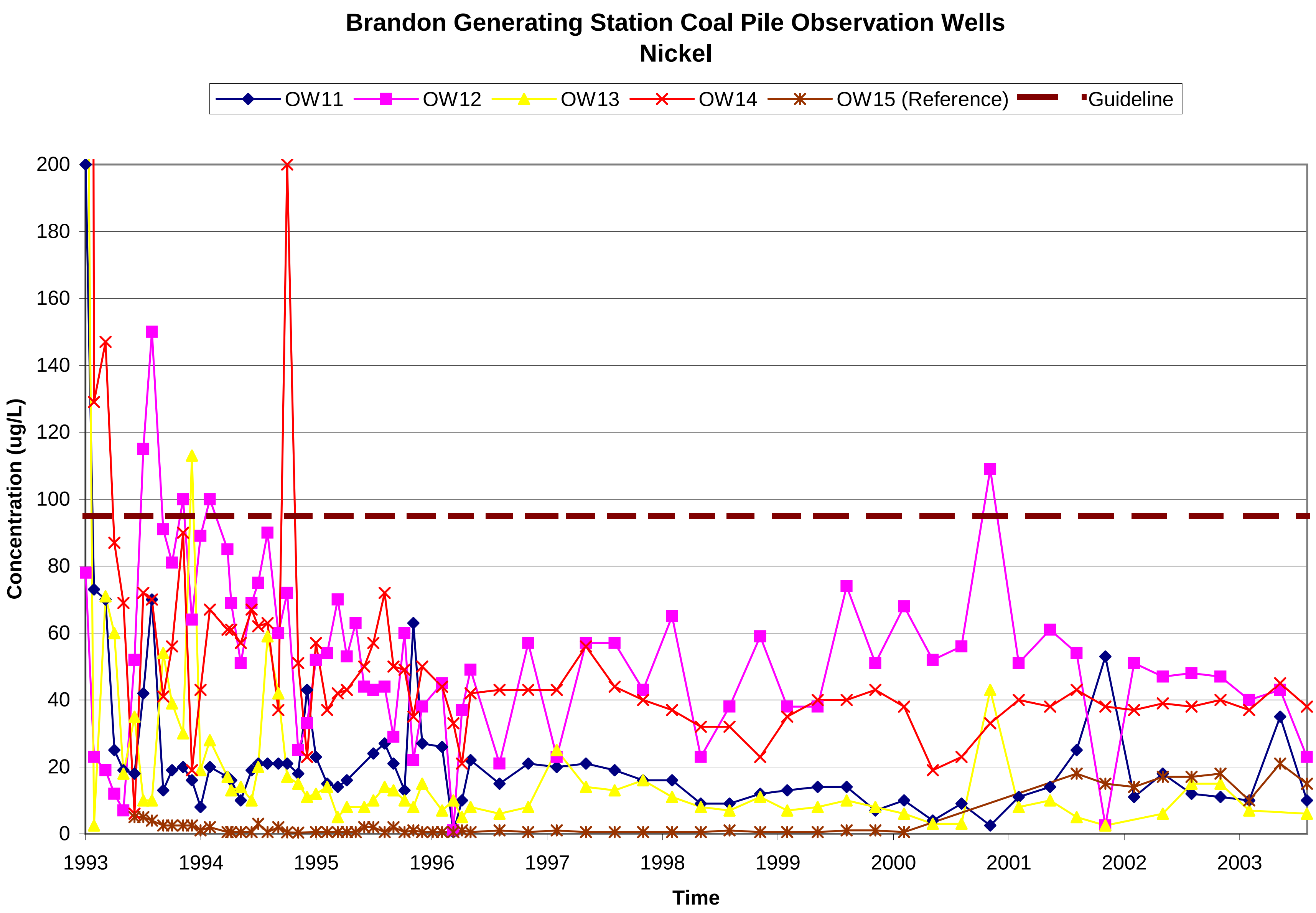

Brandon Generating Station Coal Pile Observation Wells
Nickel
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (ug/L)
200
180
160
140
120
100
80
60
40
20
0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-55

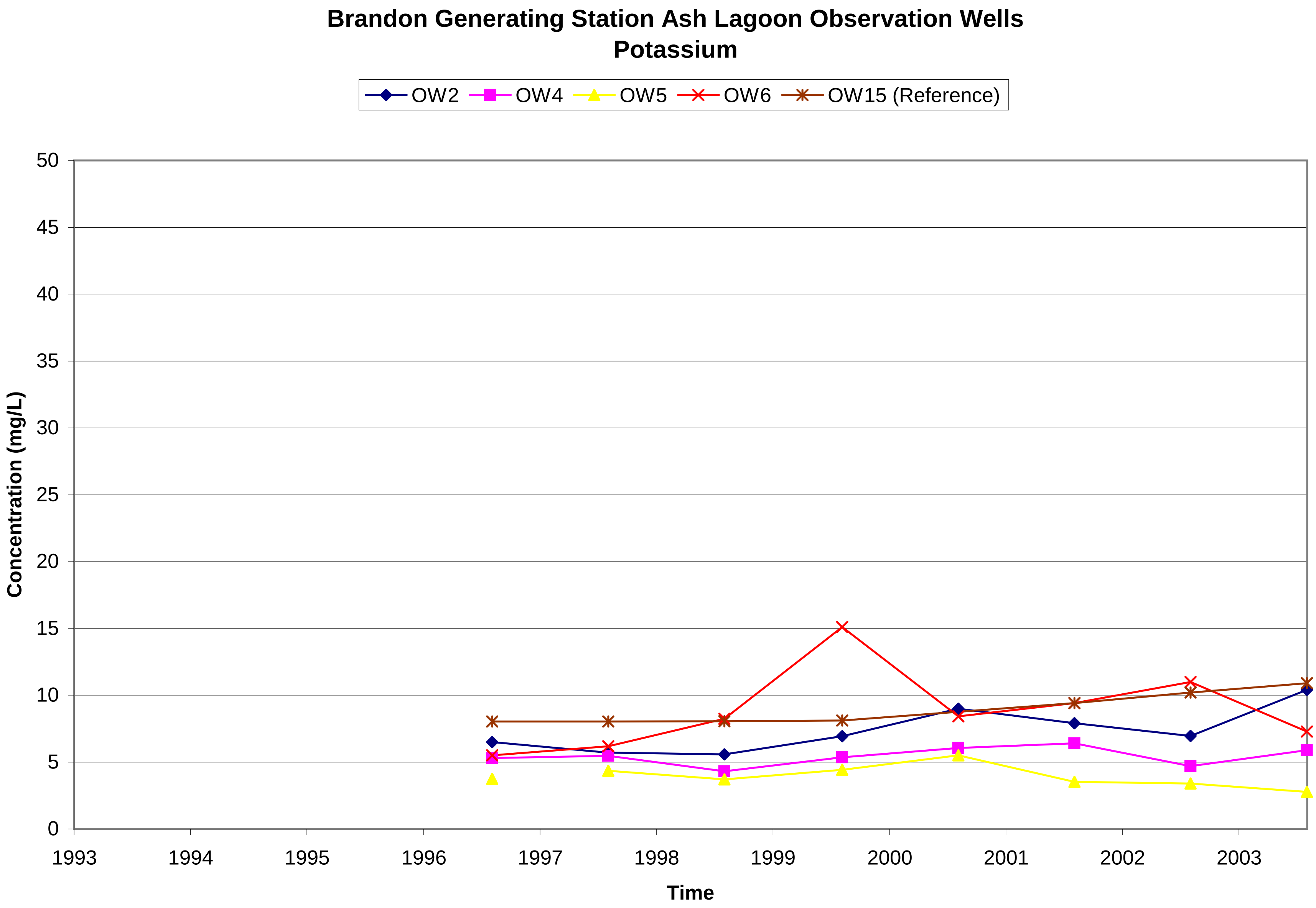

Brandon Generating Station Ash Lagoon Observation Wells
Potassium
OW2
OW4
OW5
OW6
OW15 (Reference)
Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-56

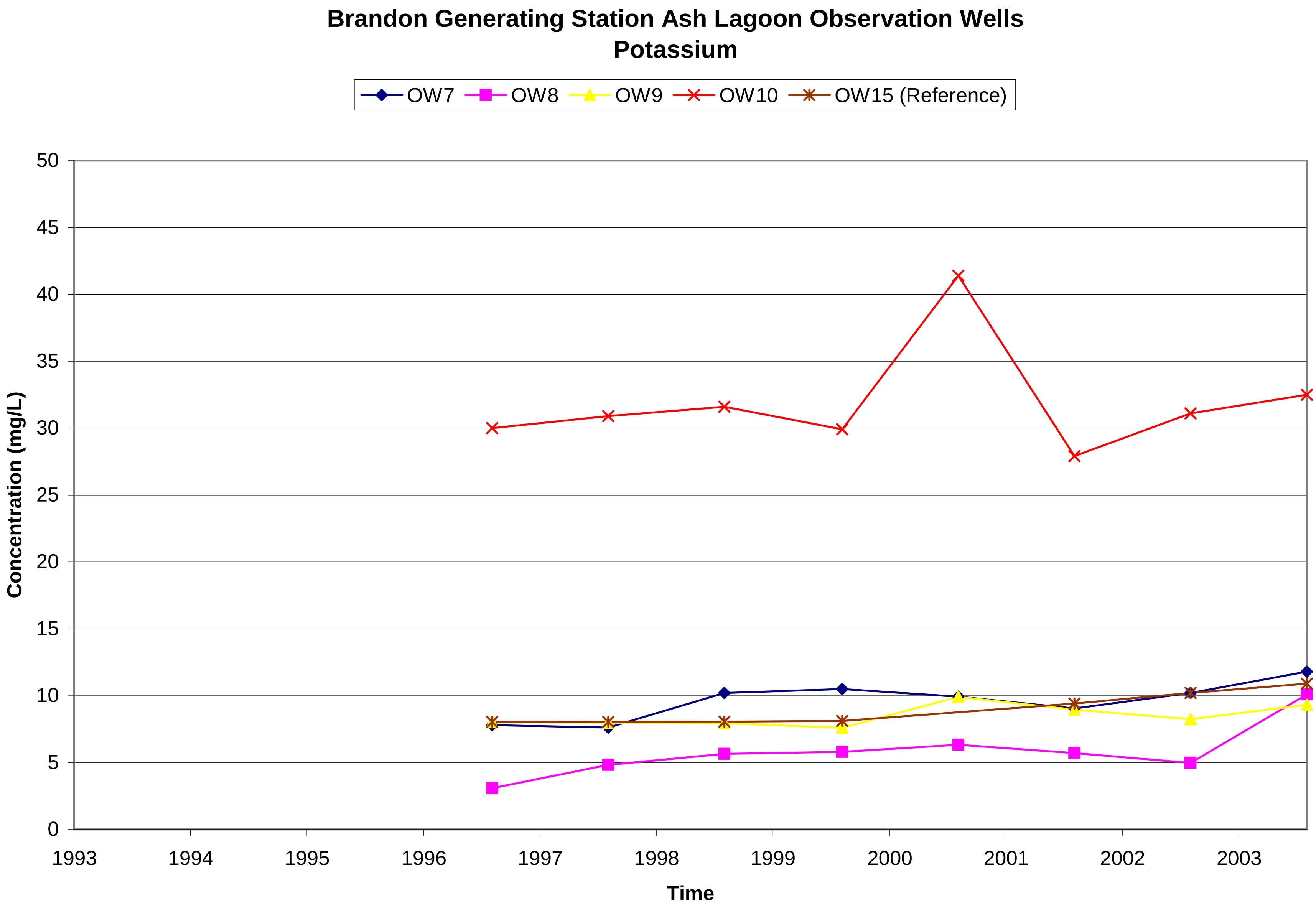

Brandon Generating Station Ash Lagoon Observation Wells
Potassium
OW7
OW8
OW9
OW10
OW15 (Reference)
Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-57

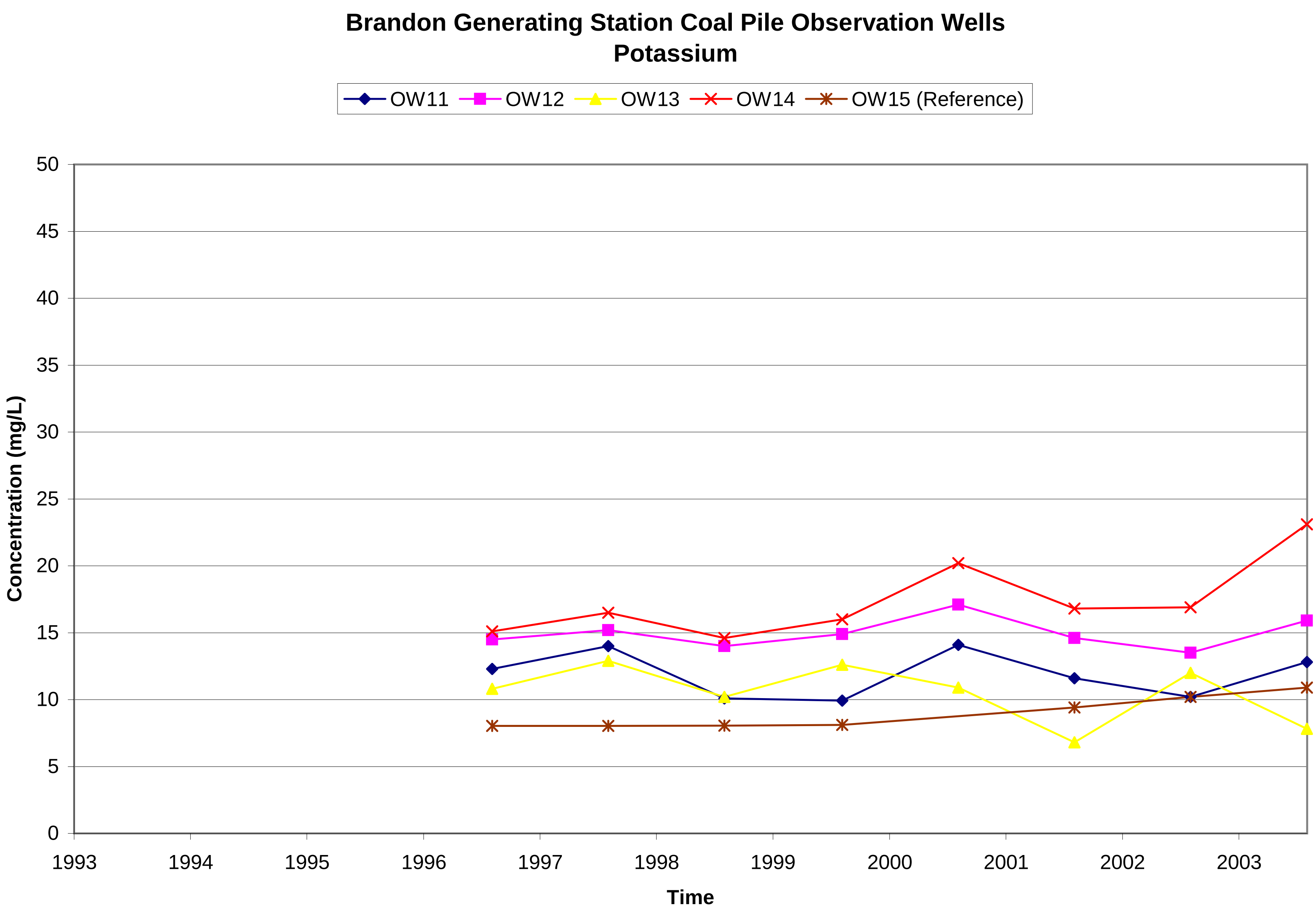
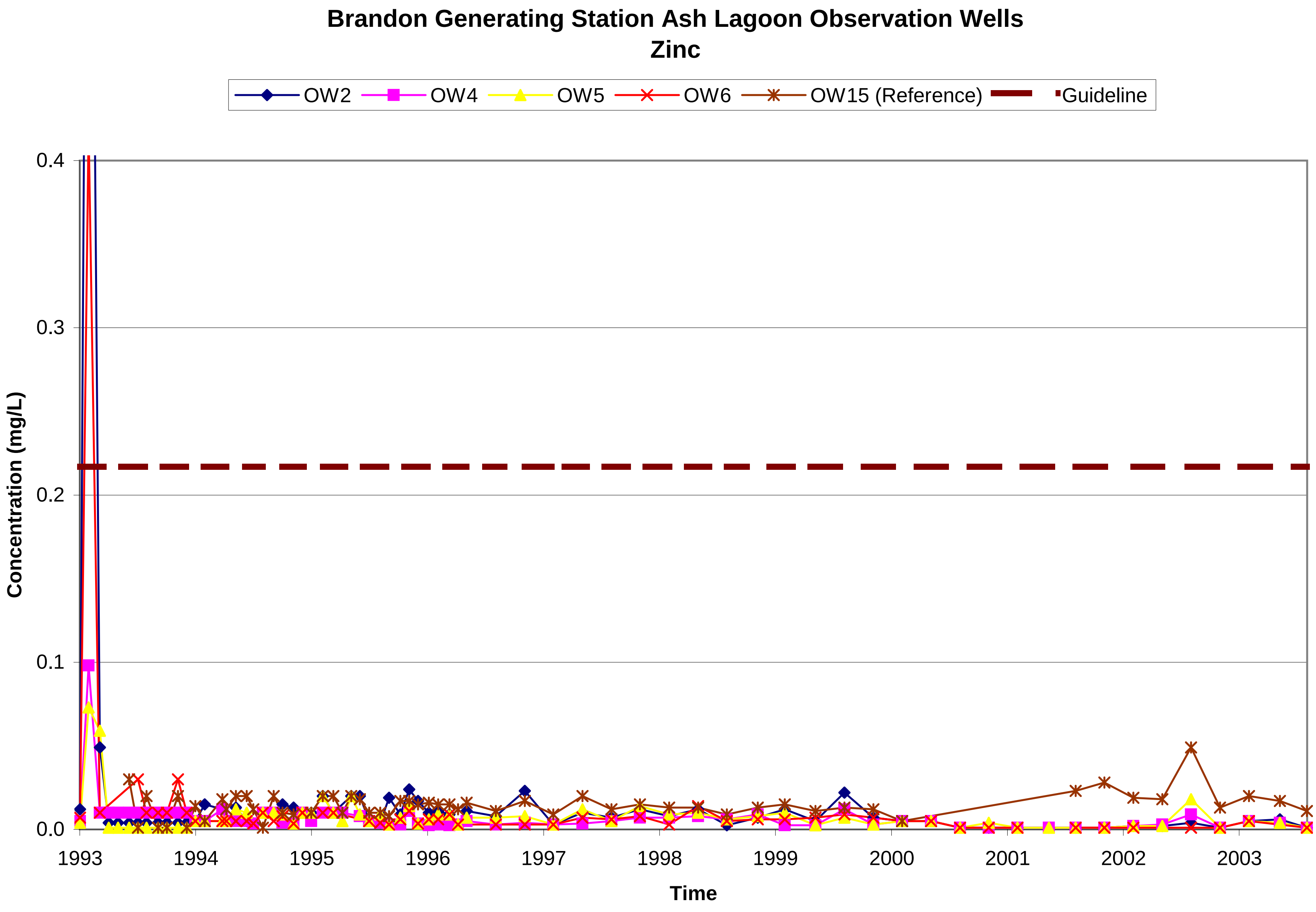
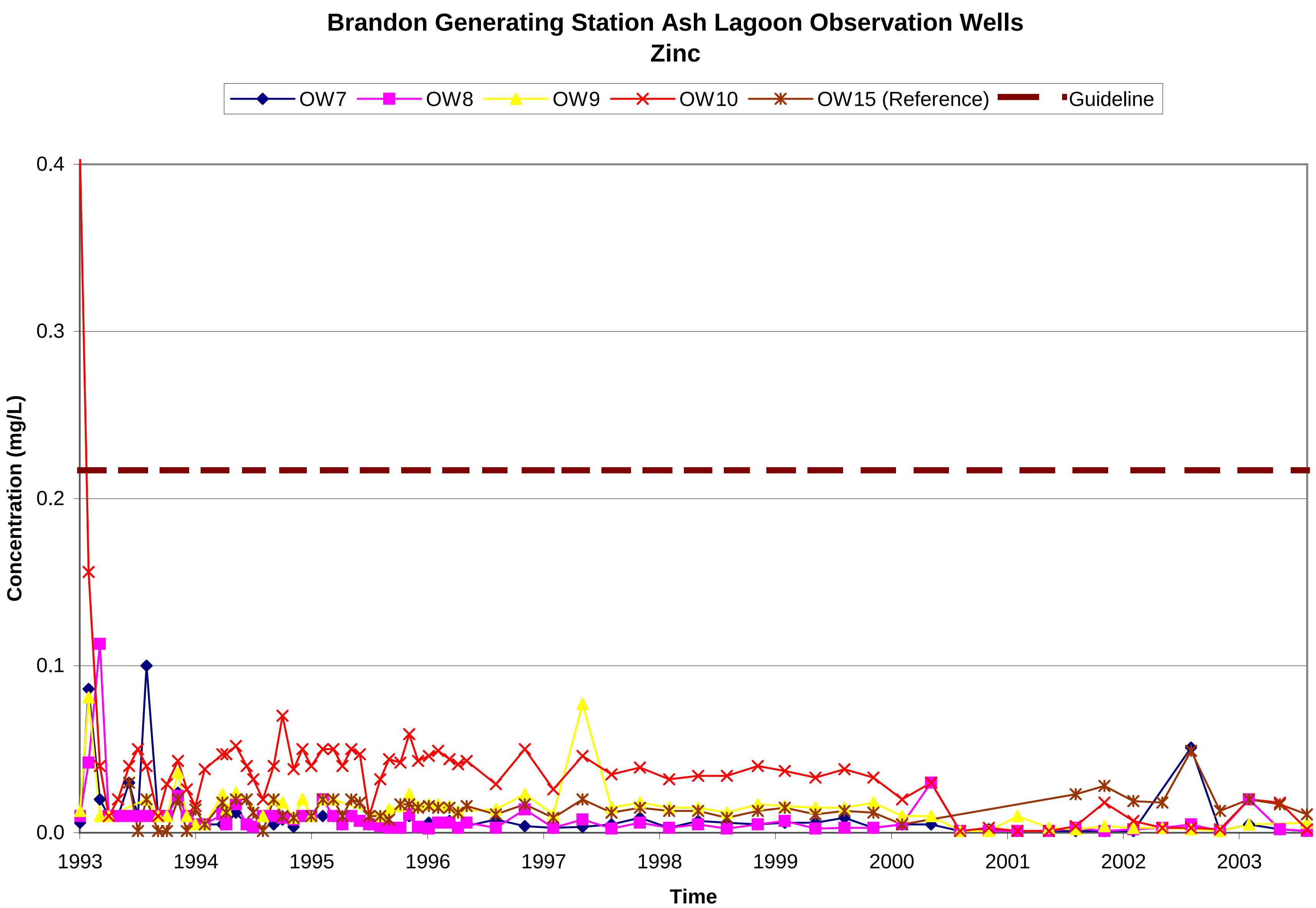

Brandon Generating Station Coal Pile Observation Wells
Potassium
OW11
OW12
OW13
OW14
OW15 (Reference)
Concentration (mg/L)
0
5
10
15
20
25
30
35
40
45
50
Time
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003

Figure A-58



Brandon Generating Station Ash Lagoon Observation Wells
Zinc
OW2
OW4
OW5
OW6
OW15 (Reference)
Guideline
Concentration (mg/L)
0.4
0.3
0.2
0.1
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-59



Brandon Generating Station Ash Lagoon Observation Wells
Zinc
OW7
OW8
OW9
OW10
OW15 (Reference)
Guideline
Concentration (mg/L)
0.4
0.3
0.2
0.1
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-60

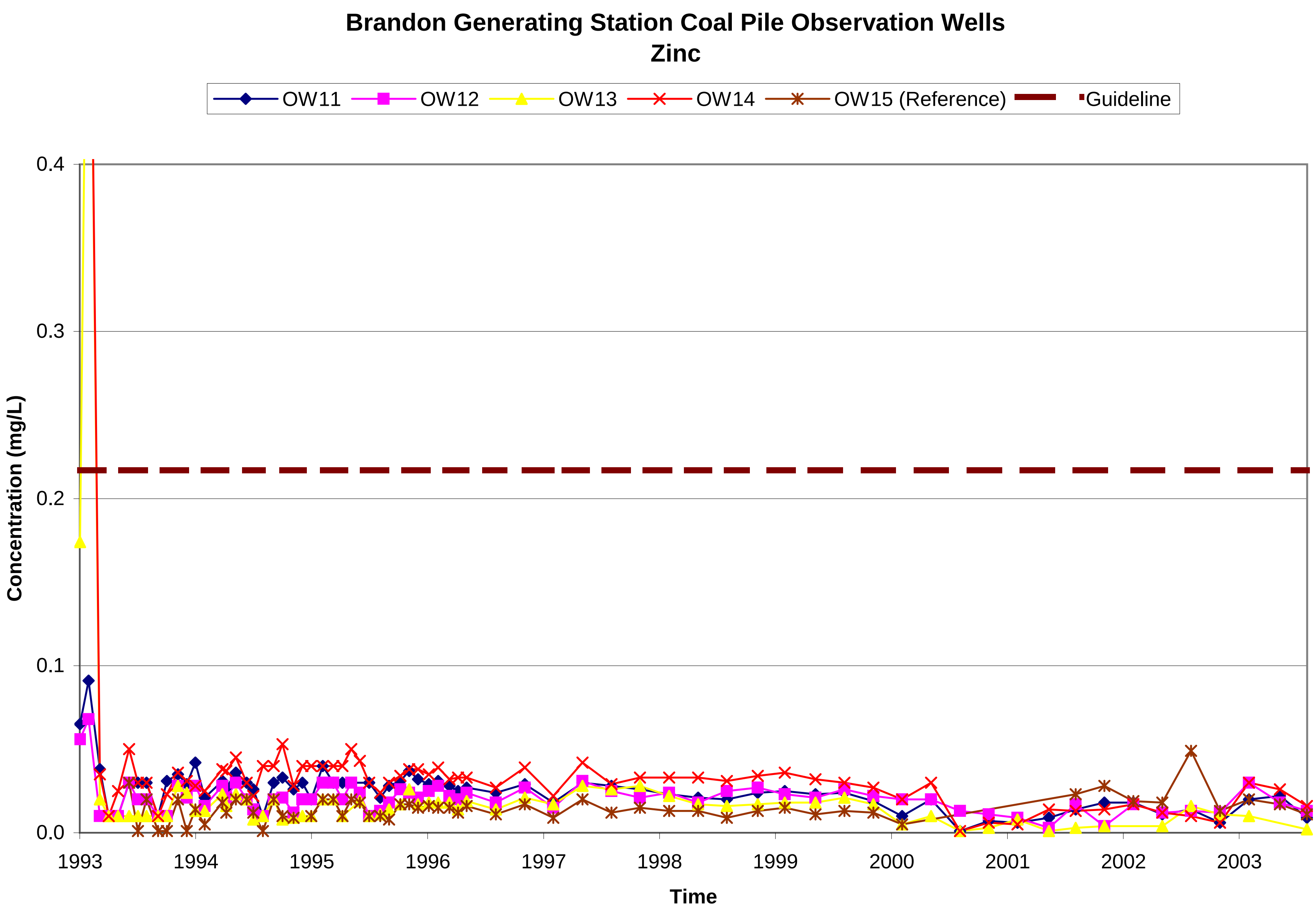

Brandon Generating Station Coal Pile Observation Wells
Zinc
OW11
OW12
OW13
OW14
OW15 (Reference)
Guideline
Concentration (mg/L)
0.4
0.3
0.2
0.1
0.0
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Time

Figure A-61