Owens Valley Vegetation Conditions 2009

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Abstract

One of the primary goals of the Long Term Water Agreement between Inyo County and the City of Los Angeles is to manage ground and surface water exportation while maintaining the groundwater-dependent vegetation communities found on the floor of the Owens Valley. These communities are particularly important because in the state of California, groundwater dependent communities such as alkali meadow are rare, comprising only 0.1 % of the state's vegetation (Davis et al. 1998). This report addresses two main questions using the reinventory data sampled through 2009. First, what is the status of the 2009 perennial vegetation cover compared with baseline conditions? Second, because of water management, which moisture source correlates more strongly with observed vegetation cover variation, groundwater or precipitation? We aim to answer these questions to provide suggestions for sustainable water management in the Owens Valley that will maintain healthy and stable native groundwater dependent vegetation communities. The 2009 reinventory data suggest perennial vegetation subject to groundwater exportation has generally decreased when compared with baseline sampling. This decline in vegetation can be attributed to deepening of the water table. We suggest improving management practices to reduce impact in rare alkali meadow habitat on the valley floor.

Introduction

This report is an analysis of the 2009 vegetation conditions monitored by the Green Book Line Point Monitoring (LPT) program. The Water Department is charged with monitoring vegetation conditions to ensure that the goals of the Long Term Water Agreement (LTWA) between the City of Los Angeles Department of Water and Power (LADWP) and Inyo County are met. According to the technical appendix to the LTWA (the Green Book), "groundwater pumping and changes in surface water management practices will be managed with the goal of avoiding significant decreases and changes in Owens Valley vegetation from conditions documented in 1984 to 1987". The conditions documented during the 1984-87 mapping effort are the baseline for the LTWA, and will hereafter be referred to as the 'baseline'.

Much of the Owens Valley floor is dominated by phreatophytes, which are species primarily dependent on shallow groundwater for moisture and drought tolerance. Non-riparian phreatophytes are often especially dependent on groundwater availability in years with a particularly dry climate (Sorensen et al., 1991; Steinwand, et al., 2006). The LTWA requires that these phreatophytic vegetation communities mapped during the baseline period should be maintained so as to not change to a drier vegetation class, than that determined by the baseline mapping. It is therefore the goal of ICWD to identify and monitor locations where vegetation communities could be altered by groundwater management, and for purposes of comparison, to also monitor locations unaffected by pumping.

Methods

Study Site—

The Owens Valley is located in east-central California and is bounded by the Sierra Nevada Mountains to the west and the White Mountains to the east. Runoff from the Sierra Nevada maintains a relatively shallow water table on the valley floor that supports large areas dominated by phreatophytic vegetation. In 2009, 100 vegetation parcels were re-inventoried out of the 2126 parcels and 223,168 acres originally mapped by LADWP during baseline. The average area of these sampled parcels is approximately 84 acres with a total of 9086 acres sampled in 2009.

Vegetation Sampling—

Each year since 1991, ICWD has reinventoried vegetation communities using randomly located transects inside vegetation parcels. During the summer of 2009, 100 vegetation parcels on the Owens Valley Floor were reinventoried to assess vegetation cover. The selection of parcels was described in previous Inyo County reports (Manning 1992, 1994). Parcels are identified based on proximity to pumping wells and potential affect of water management. Both parcels located in close proximity to wells and distant to wells are sampled, and these are generally classified as wellfield and control parcels respectively.

Because ICWD is charged with monitoring the affect of groundwater and surface water exportation on groundwater dependent vegetation communities, we classified parcels according to the degree to which their water table was affected by groundwater pumping. Control parcels were historically not affected by groundwater exportation, while wellfield parcels are subject to the affects of groundwater pumping. These designations were assigned using the heavy pumping from 1988-1990 as a valley-wide pumping ‘experiment’. During these years, the valley experienced the heaviest pumping during the Water Agreement’s record, and this time period therefore provides an adequate test of the affects to both the aquifer and vegetation within mapped parcel boundaries. Parcels were categorized as wellfield or control based on groundwater modeling shown on the baseline maps and ordinary (OK) kriging of measured water levels since 1986 (Danskin 1998; LTWA Appendix; Harrington and Howard 2000; Harrington, 2003), where data were reliable to determine effects of pumping on the water table. A reliable kriged depth to water (DTW) estimate depends on an ample number of test wells present near the parcel. Parcels that were outside of the 10ft drawdown contour based on groundwater modeling and experienced $\leq$ 1m of drawdown based on kriged DTW estimates between the time period 1986-1991 (the period of greatest drawdown in the Owens Valley) were considered controls, while all other parcels were designated as wellfield parcels, subject to potential affect from groundwater management. All parcels in the wellfield category do not necessarily have depressed water table conditions, but were affected by pumping in the past and could be affected in the future.

Approximately 19 to 41 transect start points and vectors were randomly generated in each of the 100 parcels using ArcView GIS 3.3 software (ESRI, 1992-2002). A 10, 20 or 30 meter buffer was applied to the boundary of each parcel to ensure random start points were located adequately inside the parcel boundary. The size of the buffer depended on the size and shape of each parcel. Narrow, long parcels received a 10m buffer while larger, wider parcels received a 30m buffer. Sixteen percent of parcels received a 10m buffer, 45% received a 20m buffer and 39% received a 30m buffer.

Random transects that failed to meet the following criteria were removed: transects that crossed another transect, parcel boundaries, roads, creeks, rivers, canals, ditches, the LA Aqueduct or easement, Caltrans or county road easements, areas of heavy equipment use or construction, cattle feed trough areas, or artesian springs. A minor amount of field culling occurred if any of the above issues were not apparent in the GIS, but were obvious on the ground. Field staff recorded final transect locations and bearings.

Spectral Mixture Analysis (SMA) vegetation cover estimates (Elmore et al., 2000) are also presented for all parcels from the baseline year sampled through 2009. SMA is a vegetation index that uses remotely sensed data to provide a parcel-level average cover value. In the spring of 2009, Dr. Elmore provided an updated version of the SMA measurements for all years, which are presented in this report (see Appendix 1).

Creation of Vegetation Database—

Prior to 2010, Inyo County's vegetation data was maintained in spreadsheet format. During the first half of 2010, ICWD staff uploaded and organized these data into database format. Database formats offer several advantages over spreadsheets for data storage, manipulation, and retrieval. During this process, the data and the database were subjected to quality control procedures, and several improvements to the ICWD vegetation dataset were made. Species codes and scientific names were updated to follow current Jepson Manual conventions, and species status was updated including lifeform, and lifecycle designations. Quality control and assurance procedures were applied to the entire dataset. Using our geographic information system, vegetation transects for which any part of the transect fell outside of the parcel boundary during the 1991-2009 reinventory period were identified and removed. This resulted in the removal of 1075 reinventory transects sampled between 1991-2007, with the majority of transects occurring before 2002; no transects in 2008 or 2009 fell outside of parcel boundaries. This database will be used to house all future LPT vegetation data collected by ICWD, and is still being refined.

Data Analysis—

Control vs Wellfield--

Because the goal of vegetation monitoring is to compare reinventory vegetation conditions to the baseline measurements, a repeated measures analysis is appropriate. When the same locations are repeatedly sampled over time, comparison of data within a parcel between years is not independent (i.e. the same parcel or subject is repeatedly measured). That is, there is likely some amount of spatial auto-correlation of the vegetation cover data within a parcel between years. Repeated measures Analysis of Variance (ANOVA) accounts for this correlation and provides a more reliable assessment of vegetation change than analyses that ignore this correlation.

To assess whether groups of parcels have changed over time as a result of differing groundwater management, repeated measures Multivariate Analysis of Variance (MANOVA) was performed. The average cover of all transects within a year for each parcel in the group (i.e. control or wellfield) was used to test the affect of both time and treatment (depth to groundwater) on vegetation cover. This multivariate analysis method was chosen because there are two factors, time and treatment. MANOVA allows the affect of both factors to be considered simultaneously, while accounting for the correlation between years within individual vegetation parcels. The set of parcels has varied since 1991 primarily due to staffing availability and technological improvements, which have allowed more parcels to be sampled in subsequent years. A varying sample set can confound the analysis of changes over time as well as comparisons between years within each category. Parcels that were sampled each year between 1992-2009 were analyzed ($n_T = 45$) because this sample size was much greater than the set of parcels that were consistently sampled from 1991-2009 ($n_T = 21$). In addition, a MANOVA was applied to all alkali meadow parcels sampled each year from 1992-2009, to test the difference over time between control and wellfield parcels for that vegetation community ($n_T = 27$).

To test the pairwise difference of each group's yearly mean cover compared with baseline, we used Tukey's HSD ($n_T = 45$; total sample size, $n_W = 32$ and $n_C = 13$; sample size for wellfield and control categories respectively). This test is parametric, and was chosen because it controls the alpha, or significance level (the accepted likelihood of error), when multiple pairwise comparisons are performed. When multiple comparisons are made simultaneously, the probability of making a type I error increases (with each added pairwise test, we are more likely to reject the null hypothesis of no difference and incorrectly conclude there is a difference between groups). For example, paired t-tests are inappropriate because the experiment-wise error rate is not controlled when several t-tests are employed. Tukey's HSD corrects for this problem by controlling the overall experiment-wise error rate, or the probability of making at least one type I error when performing the whole set of comparisons. A Permutational ANOVA would also be appropriate because it is an exact test, but Tukey's is a slightly more statistically conservative test, and results generated with Permutational ANOVA were generally consistent with those presented in this report. An ANOVA with Tukey's HSD was also applied to all alkali meadow parcels sampled from 1992-2009 to detect differences between each year and baseline ($n_T = 27$, $n_W = 17$ and $n_C = 10$ for wellfield and control parcels respectively).

To investigate the affect of depth to water measurements on control and wellfield parcels, a simple linear regression was applied to parcel mean perennial cover and kriged DTW measurements for the set of parcels sampled each year from 1992-2009. Because kriged DTW estimates were unreliable for the parcel MAN060 due to its distance from test wells, it was excluded.

Parcel Scale Analysis--

Two main questions were considered at the parcel scale. First, to address whether changes in groundwater levels have affected vegetation cover within particular parcels, regressions of perennial cover against DTW measured using kriged (OK) estimates, winter precipitation and water year precipitation were applied to the set of parcels sampled each year from baseline to 2009. Precipitation measurements were collected by LADWP at weather stations since at least 1935, and for one station in Big Pine, since 1971. These data provide a complete record from the baseline monitoring through present. The nearest weather station to each parcel was chosen, except when two weather stations were both within a mile of a parcel and an average of the two stations was used. For parcels on the Blackrock USGS quad, the LA aqueduct rain gauge was not used because the regression between the nearest ICWD gauge and the LA aqueduct gauge was less robust than either the Tinemaha Reservoir or Independence yard weather stations (with r^2=0.93 and r^2=0.96 respectively). Second, to determine which of the two moisture sources (groundwater or precipitation) were more important to predict parcel cover; a multiple linear regression of DTW and winter precipitation was applied.

Results

Control vs Wellfield—

Wellfield parcels behaved differently over time when compared with control parcels. A significant interaction was found between time and parcel type (i.e. control or wellfield) using the set of parcels sampled from 1992-2009 (Figure 1, n = 45, P = 0.0084; Where P is the probability of obtaining an observed result as extreme as the one that was actually observed, assuming that the null hypothesis of no difference is true. A p-value less than 0.05 is unlikely due to chance). Mean wellfield parcel cover is below baseline for most of the years since baseline measurements, while mean control parcel cover has been above its baseline during the same period. The same general pattern is evident when alkali meadow parcels are examined, but the test is not significant (P = 0.17) likely due to the reduced sample size causing a reduction of statistical power.

Average perennial live cover in wellfields decreased between the baseline year and 2009 by 4.8%, while control perennial live cover decrease is minute; measuring 0.3% (Figure 2). Pairwise testing of all reinventory years indicates that over time, vegetation cover has generally declined in wellfield parcels when compared with baseline measurements, while control parcel percent cover has increased (Figure 2, P < 0.0001). This pattern is consistent for alkali meadow parcels sampled during the same time period (Figure 2, P < 0.0001).

A regression of all wellfield parcel cover against depth to groundwater under these parcels is also significant (Figure 3, r^2 = 0.24, P <0.0001). Although the relationship is weak, generally as DTW increases, wellfield vegetation cover decreases. However, when control parcel cover was regressed against depth to water, there was no relationship, indicating that variation in depth to groundwater affects wellfield parcels, but not control parcels (Figure 3, r^2 = 0.08, P = 0.17).

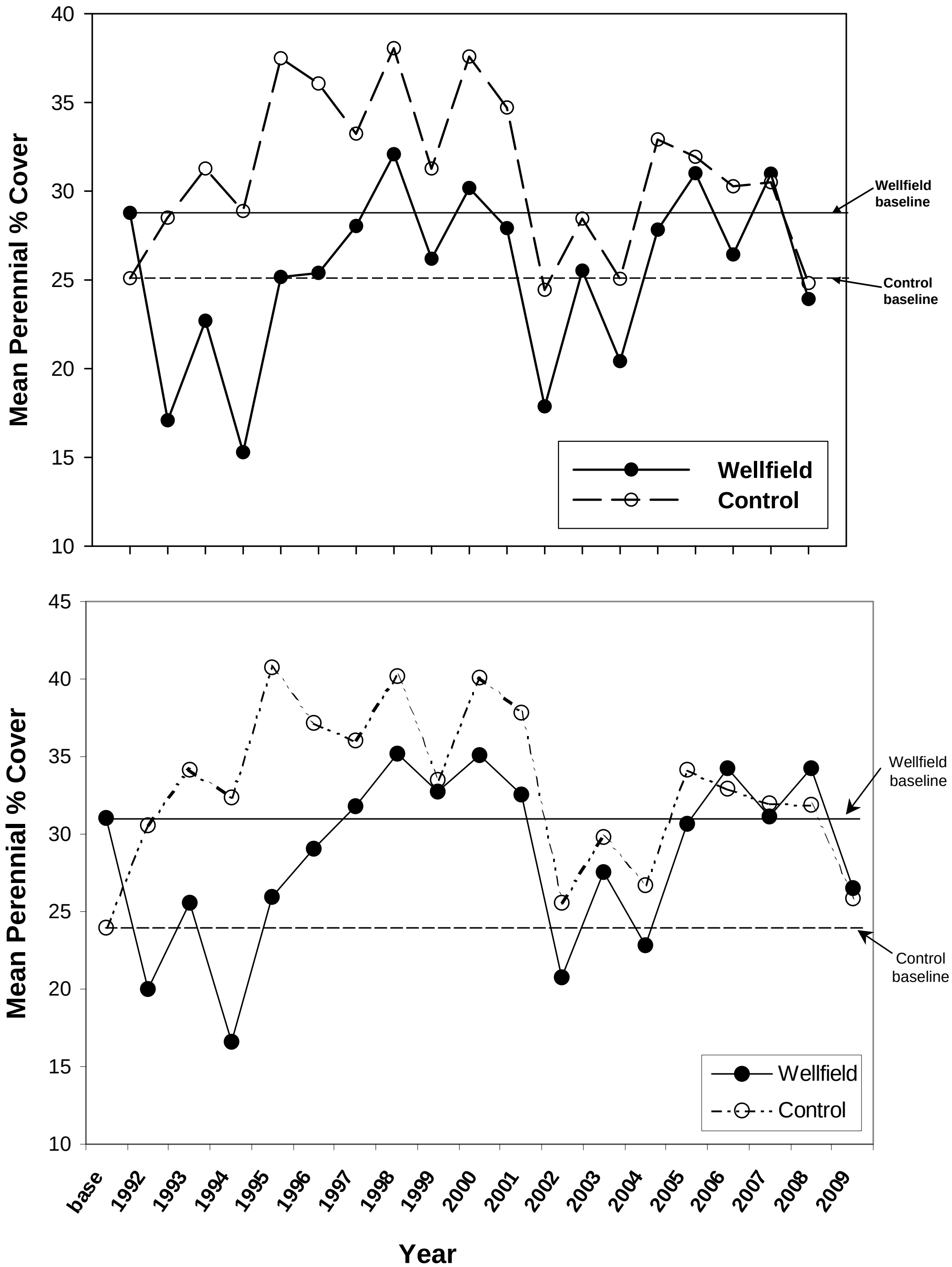


Figure 1. Repeated Measures MANOVA analysis of ***a)*** all parcels sampled from the period 1992-2009 the interaction of time and parcel type is significant for the years 1992-2009, indicating that control parcels behave differently than wellfield parcels with respect to time (P = 0.0084). ***b)*** alkali meadow parcels sampled during the same time period. The interaction of time and parcel type is not significant (P = 0.17), although the general pattern is the same; control parcels are above while wellfield parcels are generally below baseline.

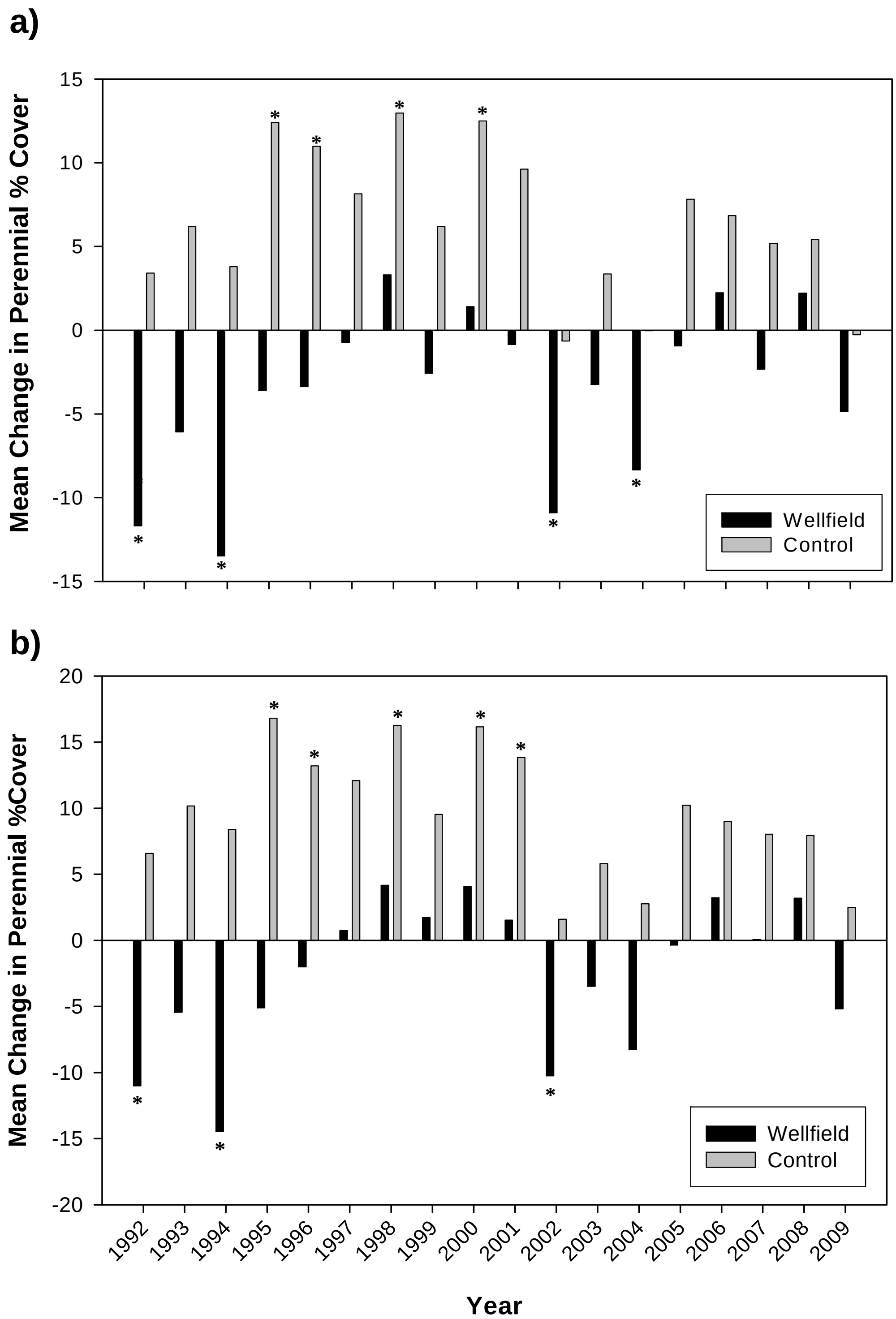
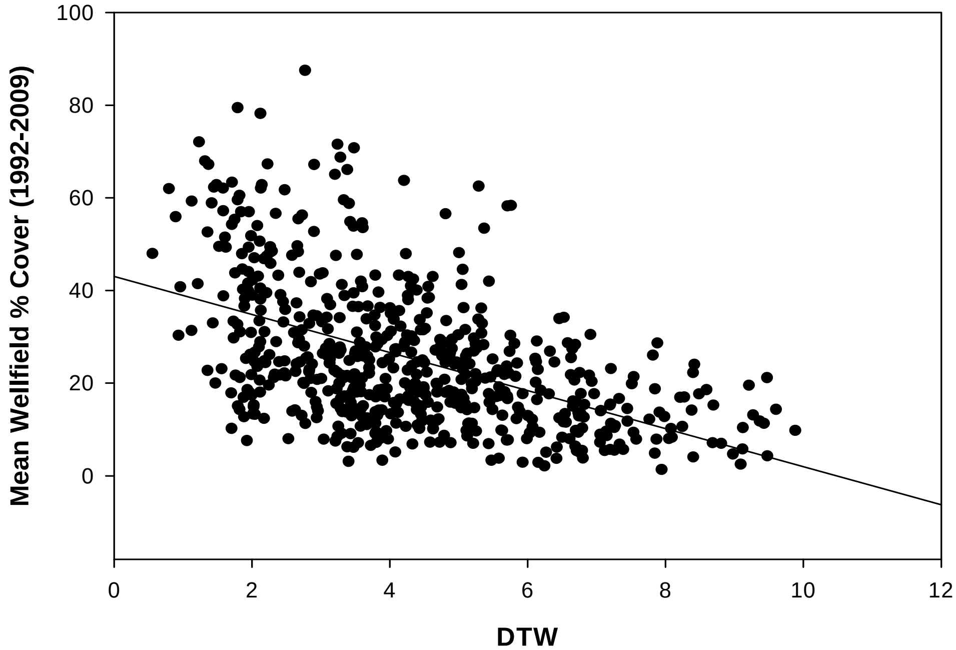


Figure 2. Change in vegetation cover compared to baseline for wellfield and control parcels measured by the Green Book line point program ***a)*** for the subset of parcels visited every year since 1992 and ***b)*** for the alkali meadow parcels sampled each year since 1992. Asterisks denote instances where change in mean cover was significantly different from zero ($P \leq 0.05$, ANOVA with Tukey's HSD).



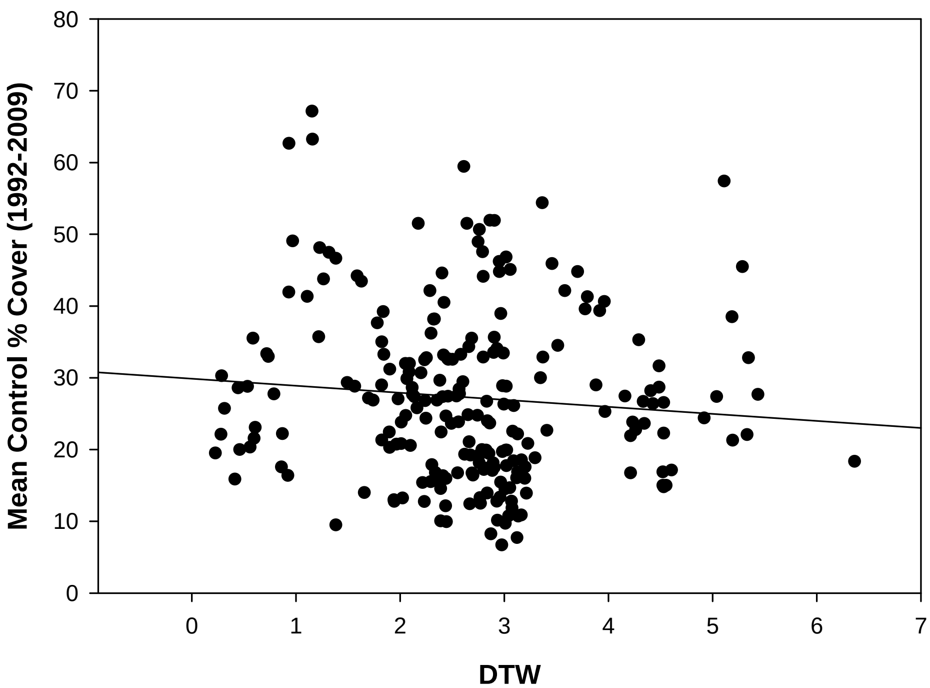


Figure 3. Mean wellfield and control parcel vegetation cover regressed against average parcel depth to groundwater (DTW) for the set of parcels reinventoried each year between 1992-2009. As DTW increases in wellfield parcels, vegetation cover decreases ($r^2 = 0.236$, $P < 0.0001$), while no relationship is generally found between control parcels and observed changes in depth to groundwater ($r^2 = 0.008$, $P = 0.17$).

Parcel Scale Examination—

According to simple linear regression for the set of parcels sampled from 1992-2009, wellfield parcels are more affected by depth to groundwater than by precipitation. In 41% of wellfield parcels perennial cover was significantly correlated with DTW, while in only 23% of control parcel cover was correlated with changes in DTW (Table 1). Most wellfield parcels, 84%, that were correlated with DTW were not correlated with precipitation. In addition, the average r^2 associated with wellfield parcels (r^2 = 0.43) where DTW was significantly correlated with perennial cover is stronger than for respective control parcels (r^2 = 0.33), while the opposite is true for precipitation. The mean r^2 associated with wellfield parcels where precipitation was significantly correlated with perennial cover (r^2 = 0.33, and 0.37 respectively for winter- and water year precipitation) is weaker than for respective control parcels (r^2 = 0.43 and 0.41 respectively for winter- and water year precip). No parcels showed both DTW and precipitation were correlated with cover according to simple linear regression. According to multiple linear regression, however, several wellfield parcels show both DTW and precipitation explained changes in vegetation cover. Of these, 55% indicate that DTW explained more variation in perennial cover than precipitation, while only 27% of parcels show winter precipitation explained more variation in perennial cover than DTW, and 18% demonstrated equal correlation with both variables. Seven wellfield parcels examined in this analysis were strongly correlated with DTW, and maintain an r^2 greater than or equal to 0.5 (Table 1). In these parcels, perennial cover is more affected by changes in moisture availability from groundwater rather than from changes in precipitation. The two parcels most correlated with changes in depth to groundwater are LAW063 and LAW 107 (Table 1, Figures 4a and 4b).

Parcel-scale graphs for each parcel reinventoried in 2009 are presented in Appendix 1 with three data sets; average yearly parcel cover as measured by the line point reinventory program, updated SMA average cover data, and kriged (OK) depth to water estimates (Figures 1-100).

Table 1. Results of both simple and multiple linear regression (MLR) analysis of mean perennial cover regressed against depth to groundwater, winter precipitation, and water-year precipitation for parcels sampled each year from 1992-2009. Bold text and shading indicate significant regressions at the α = 0.05 level (r^2 and P values are given); where two regressions are significant in the MLR, bold text indicates the predictor that demonstrates a stronger correlation with perennial cover.

		Cover x DTW		**Cover x Winter Precip**		**Cover x WY Precip**		**MLR: Cover x DTW and Winter Precip**			
c/w	**PCL**	***r^2***	***p***	***r^2***	***p***	***r^2***	***p***	**dtw *r^2***	**dtw *p***	**precip *r^2***	**precip *p***
C	BGP031	**0.439**	**0.002**	0.03	0.4725	0.054	0.338	**0.439**	**0.0011**	0.0701	0.149
C	BLK115	0.0989	0.189	0.0068	0.734	0.03	0.46	0.099	0.189	n/a	n/a
C	FSL187	0.147	0.128	0.022	0.541	0.041	0.401	0.147	0.128	n/a	n/a
C	IND096	0.014	0.629	**0.479**	**0.001**	**0.455**	**0.0015**	n/a	n/a	**0.48**	**0.001**
C	IND163	0.00003	0.981	**0.435**	**0.0021**	**0.492**	**0.0008**	0.091	0.098	**0.435**	**0.0006**
C	LNP018	0.0028	0.827	0.126	0.134	0.063	0.296	n/a	n/a	0.126	0.134
C	MAN060	0.021	0.571	0.0011	0.891	0.031	0.47	n/a	n/a	n/a	n/a
C	PLC024	0.166	0.082	0.2	0.054	**0.272**	**0.022**	0.2	0.118	0.116	0.0795
C	PLC106	0.177	0.586	0.00004	0.97	0.001	0.85	n/a	n/a	n/a	n/a
C	PLC121	**0.26**	**0.025**	0.014	0.627	0.013	0.637	**0.261**	**0.025**	n/a	n/a
C	PLC223	0.105	0.175	**0.385**	**0.0046**	**0.411**	**0.003**	n/a	n/a	**0.385**	**0.0045**
C	UNW029	0.012	0.647	0.127	0.133	0.147	0.104	n/a	n/a	0.127	0.133
C	UNW039	**0.279**	**0.02**	0.0037	0.803	0.008	0.709	**0.279**	**0.02**	n/a	n/a
W	BGP154	**0.622**	**0.0001**	0.003	0.807	0.019	0.57	**0.622**	**0.00001**	0.086	0.045
W	BGP162	**0.544**	**0.0003**	0.068	0.28	0.0782	0.246	**0.544**	**0.0003**	n/a	n/a
W	BLK009	0.026	0.504	**0.336**	**0.009**	**0.41**	**0.0031**	0.0616	0.21	**0.336**	**0.006**
W	BLK016	**0.496**	**0.0008**	0.006	0.76	0.003	0.85	**0.496**	**0.0007**	n/a	n/a
W	BLK024	0.026	0.501	**0.56**	**0.0002**	**0.588**	**0.0001**	n/a	n/a	**0.56**	**0.0002**
W	BLK033	0.06	0.31	**0.42**	**0.003**	**0.46**	**0.002**	n/a	n/a	**0.42**	**0.003**
W	BLK039	0.196	0.057	**0.26**	**0.026**	**0.25**	**0.03**	**0.29**	**0.006**	**0.26**	**0.003**
W	BLK044	0.187	0.063	0.03	0.5094	0.16	0.61	**0.29**	**0.003**	**0.34**	**0.0005**
W	BLK069	0.032	0.459	0.133	0.13	0.18	0.07	n/a	n/a	0.13	0.125
W	BLK074	0.032	0.459	**0.26**	**0.03**	**0.33**	**0.01**	n/a	n/a	**0.26**	**0.03**
W	BLK075	**0.5**	**0.0007**	0.02	0.54	0.02	0.54	**0.5**	**0.0002**	0.09	0.07
W	BLK094	**0.226**	**0.039**	**0.35**	**0.007**	**0.435**	**0.0021**	0.1658	0.02	**0.435**	**0.001**
W	BLK099	0.13	0.129	0.055	0.332	0.0029	0.8249	0.13	0.129	n/a	n/a
W	FSP006	0.035	0.437	**0.411**	**0.003**	**0.49**	**0.0009**	0.1263	0.052	**0.411**	**0.0007**
W	IND011	**0.216**	**0.045**	0.041	0.4	0.056	0.326	**0.216**	**0.045**	n/a	n/a
W	IND035	0.05	0.356	0.087	0.217	0.104	0.177	0.098	0.184	0.0879	0.121
W	IND106	0.064	0.294	**0.303**	**0.015**	**0.28**	**0.02**	n/a	n/a	**0.303**	**0.014**
W	IND111	**0.309**	**0.013**	0.155	0.095	0.02	0.56	**0.309**	**0.0005**	0.3004	0.002
W	IND132	0.135	0.121	**0.283**	**0.019**	**0.273**	**0.022**	0.3816	0.0005	**0.2834**	**0.0001**
W	IND139	**0.317**	**0.012**	0.15	0.101	0.171	0.078	**0.317**	**0.00028**	0.3194	0.00174
W	IND231	0.058	0.317	**0.209**	**0.048**	0.185	0.066	n/a	n/a	0.209	0.048
W	LAW063	**0.72**	**0.0001**	0.0005	0.921	0.0011	0.891	**0.7208**	**4E-07**	0.0864	0.016
W	LAW065	**0.503**	**0.0007**	0.015	0.62	0.02	0.55	**0.503**	**0.00003**	0.1729	0.0009
W	LAW085	0.144	0.108	0.107	0.17	0.097	0.192	**0.1446**	**0.008**	0.2868	0.012
W	LAW107	**0.662**	**0.0001**	0.036	0.437	0.038	0.4227	**0.662**	**2.3E-05**	n/a	n/a
W	LAW120	**0.265**	**0.024**	0.0007	0.912	0.0004	0.932	**0.265**	**0.024**	n/a	n/a
W	LAW122	0.136	0.12	0.0013	0.883	0.0007	0.9	0.136	0.12	n/a	n/a
W	MAN006	0.036	0.43	0.05	0.35	0.07	0.27	n/a	n/a	n/a	n/a
W	MAN007	0.063	0.302	0.207	0.0501	**0.21**	**0.044**	0.1913	0.03	**0.2074**	**0.0086**
W	MAN037	0.025	0.515	0.0004	0.935	0.003	0.822	n/a	n/a	n/a	n/a
W	TIN028	2.8E-05	0.98	**0.263**	**0.025**	**0.255**	**0.028**	n/a	n/a	**0.263**	**0.025**
W	TIN068	**0.229**	**0.039**	0.038	0.424	0.036	0.436	**0.229**	**0.039**	n/a	n/a

Note: n/a = too insignificant to report (p>0.25).

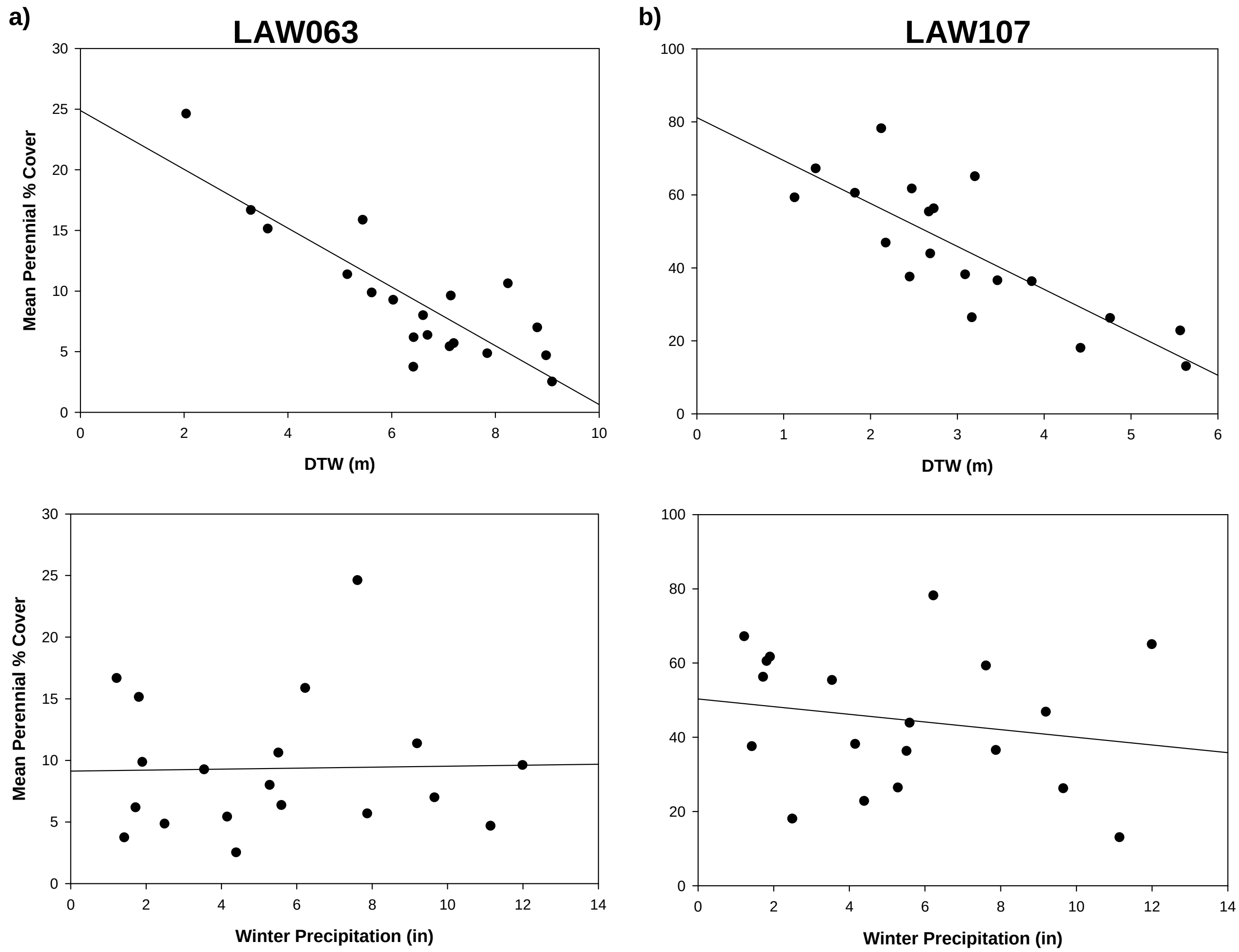


Figure 4. Linear regressions of mean perennial cover and depth to groundwater and winter precipitation in ***a)*** LAW036 and ***b)*** LAW107. Both parcels respond to changes in DTW, and not precipitation.

Discussion

The 2009 LPT reinventory provides a new dataset with which to compare baseline measurements. As might be predicted when groundwater pumping occurs in the same general locations each year, wellfield parcels generally show a greater change in vegetation over time. Parcels sampled between 1992 and 2009 indicate live cover estimates on wellfield parcels are persistently below their baseline measurements, while control parcels remain above or consistent with baseline sampling during the same period (Figures 1, 2). Currently, some of the wellfield parcels included in this analysis do not have depressed water tables, so this finding would likely be magnified if only wellfield parcels currently affected by pumping were analyzed. When alkali meadow parcels are examined, the result is similar; wellfield perennial cover has generally deceased over time, while control parcel cover has increased or remained at baseline. This is a particularly important finding given that alkali meadows are a rare habitat type in California (Davis et al. 1998).

Several regression analyses attribute deepening groundwater levels directly to changes in perennial cover. First, as groundwater depth increases, cover is generally reduced in wellfield parcels; while in control parcels, fluctuations in depth to groundwater are smaller, resulting in little correlation with groundwater fluctuations. This confirms that groundwater extraction causes a decrease in live vegetation cover in vegetation communities in wellfields. Second, parcel-scale regressions indicate that 40% of wellfield parcels exhibit decreasing perennial cover with deepening groundwater, while only 23% of control parcels show the same response because in control parcels, groundwater levels are not fluctuating as drastically. Not only are more wellfield parcels responding to deepening water tables, but the average correlation between cover and depth to groundwater is stronger in wellfield parcels (r^2 =0.43). Conversely, precipitation is more important to maintain vegetation in control parcels on average (r^2 =0.43), again likely because DTW is not fluctuating as severely in control parcels. Third, of the 11 wellfield parcels that responded to both DTW and precipitation, a Multiple Linear Regression indicated that DTW explained more variation in perennial cover than precipitation in 55% of parcels, while only 27% respond primarily to precipitation. In wellfield parcels generally, increasing DTW, or a deepening water table, caused a stronger decrease in cover than any affect of precipitation increasing or maintaining cover. It appears that where groundwater is available to plant roots (i.e. in control parcels), precipitation can enhance vegetative growth, but where the groundwater table fluctuates in and out of the root zone, vegetation is dependent on this moisture until a threshold is reached and vegetation begins to respond to precipitation events, similar to results found by Elmore et al. 2006. This could result in a change in vegetation type inconsistent with the goals of the LTWA. This is consistent with the findings of Sorensen et al (1991) who suggest that the shallow water table in the Owens valley acts as a storage bank for perennial vegetation when soil moisture supplied by precipitation is inadequate.

A shallow groundwater table is generally important to maintain healthy ground-water dependent communities such as those found on the floor of the Owens Valley. While Sorensen et al (1991) reports that plants in the Owens Valley can expand their root system to accommodate a deepening aquifer, the maximum depth these roots can extend is unknown, and a growth limit will eventually be reached. This report demonstrates that shallow groundwater may not be available on a consistent basis to vegetation parcels near pumping wells, and may be below the root zone. Water management practices need to allow recovery in heavily impacted sites and prevent further loss of ground-water dependent vegetation.

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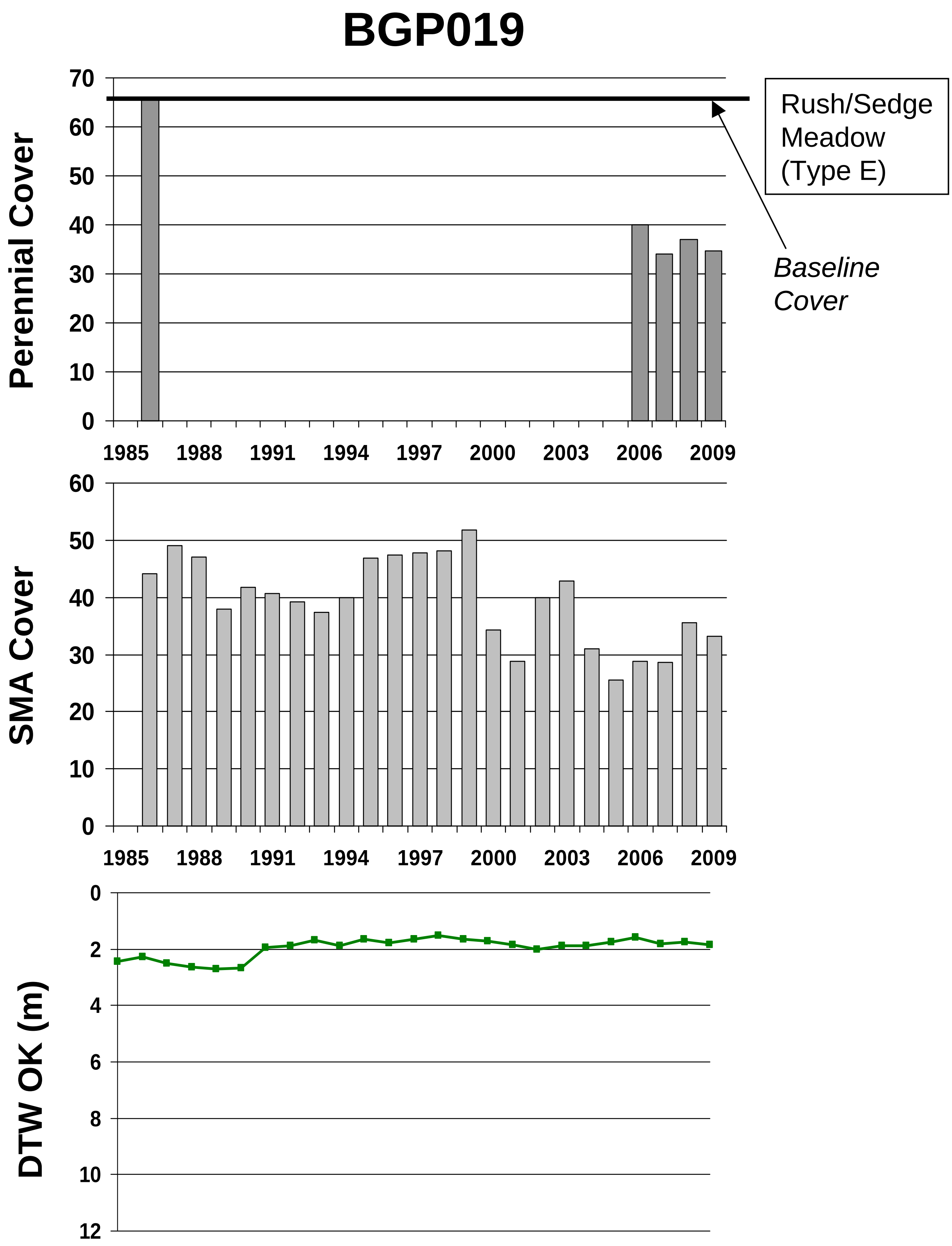
Appendix 1:

Figures 1-100 depict mean vegetation cover response over time for 100 vegetation parcels re-sampled in 2009 using the Green Book Line Point monitoring program, updated SMA average cover data, and kriged (OK) depth to water estimates.

No statistical analysis is presented to answer the question of whether individual parcel perennial cover has changed over time. A repeated measures analysis would be the most appropriate test for this question, but because the line point reinventory program uses randomly placed transects (likely due to the unknown location of baseline transects), a single transect cannot be directly compared to another in a subsequent year, so a repeated measures analysis is not possible. ICWD is currently researching this topic, and until an appropriate method is determined, parcel-level data will be presented without statistical analyses. It is the goal of ICWD to determine this method and present these analyses in the 2010 ICWD Annual Report.



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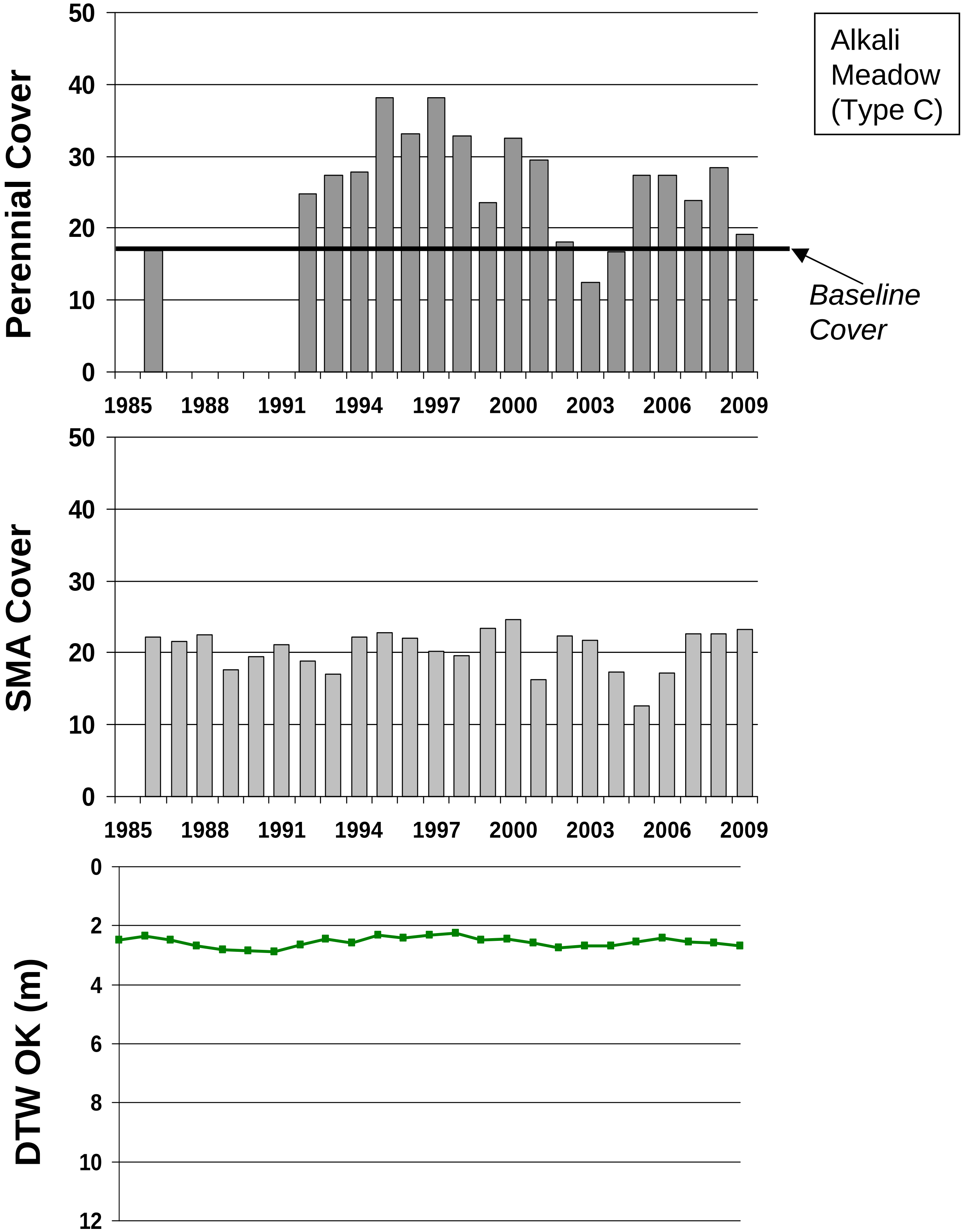

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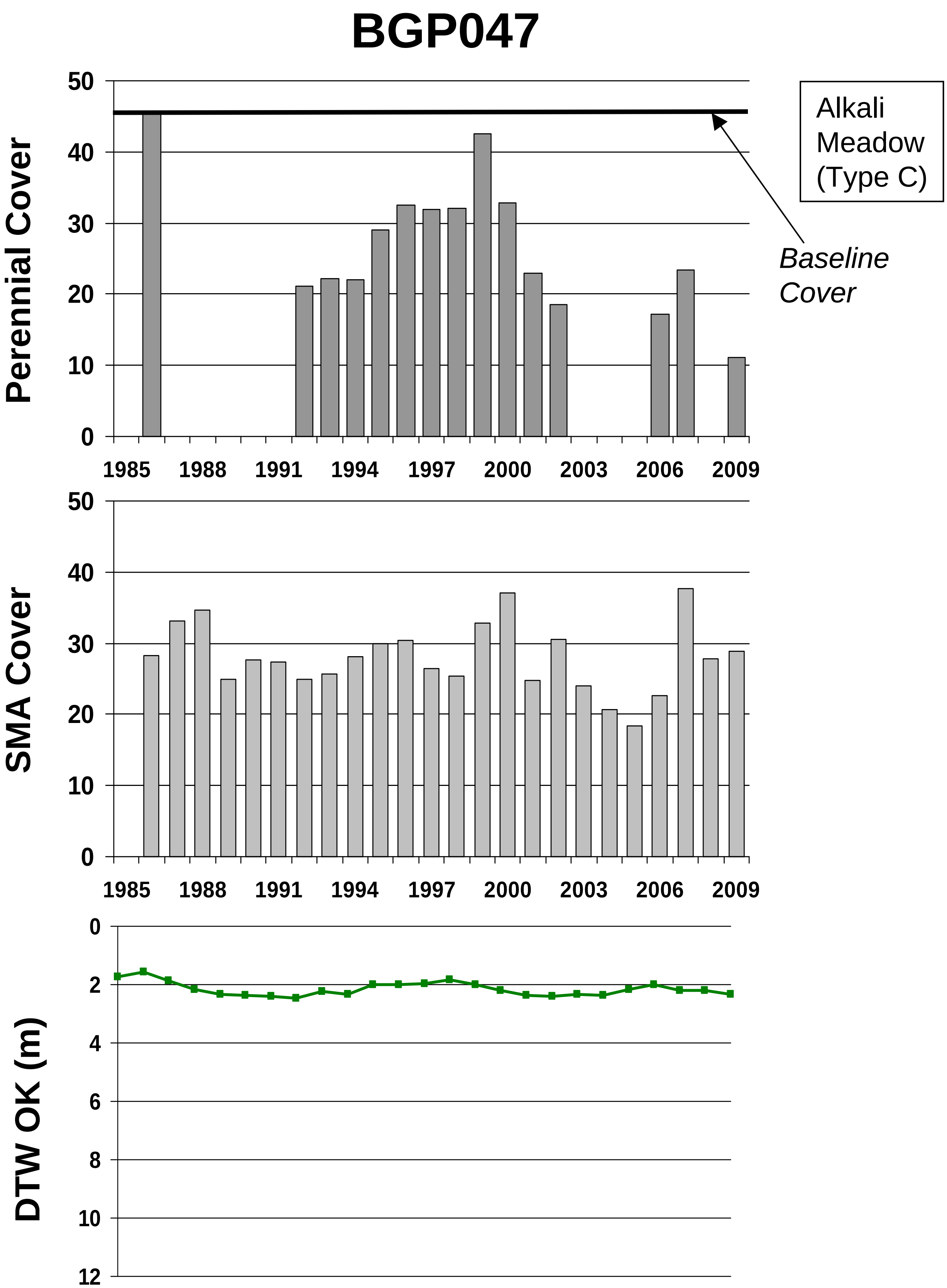

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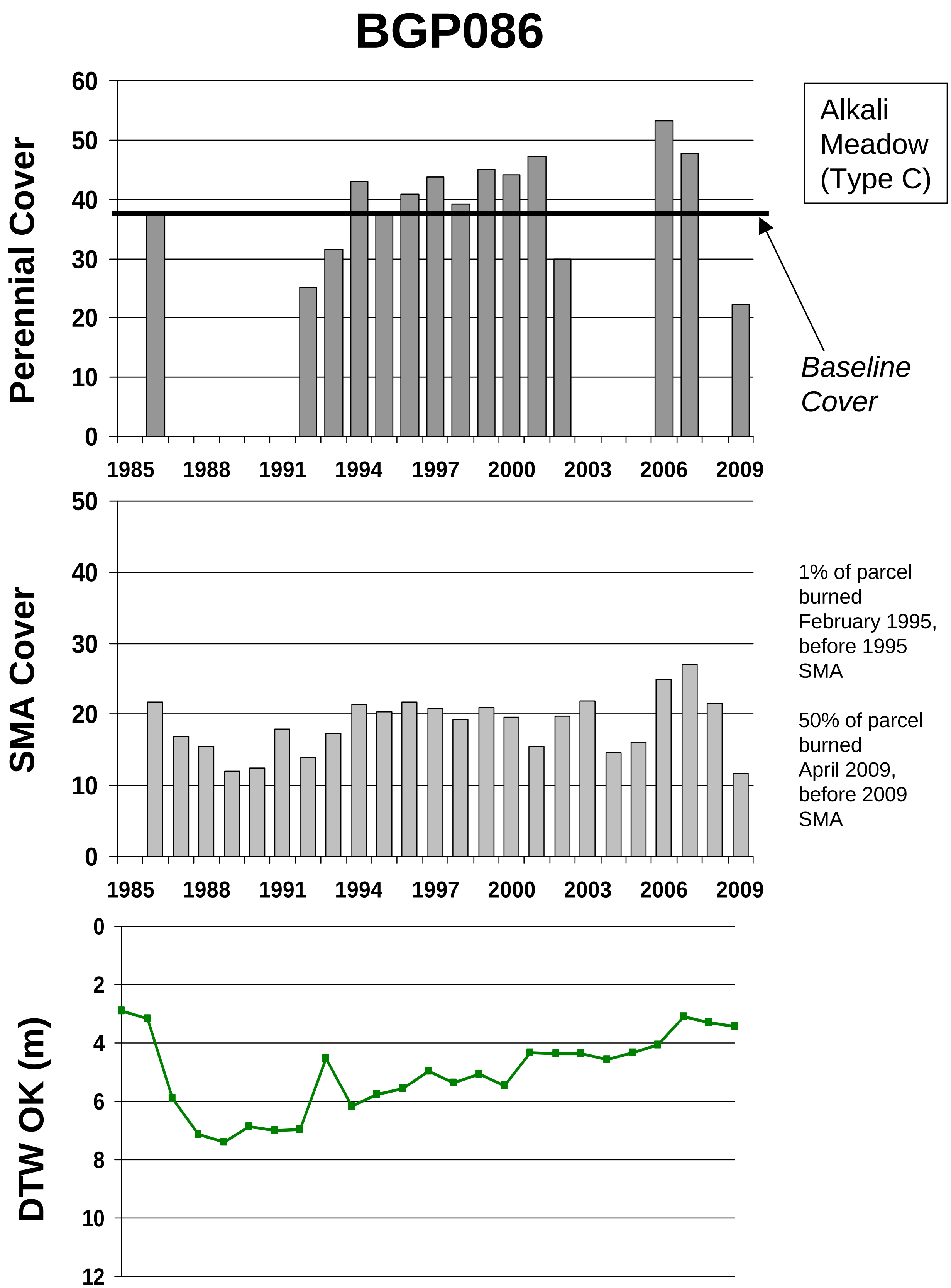

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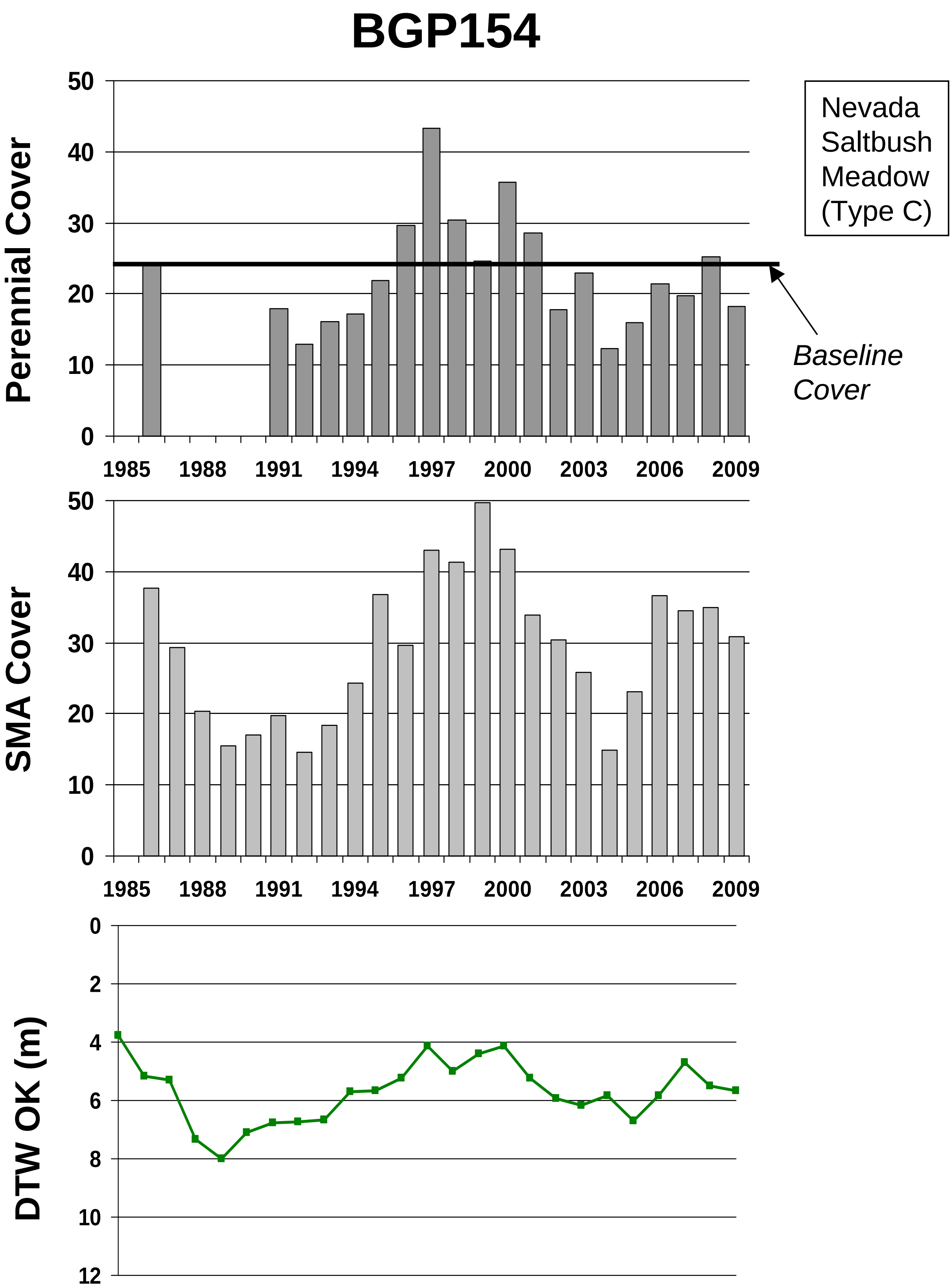

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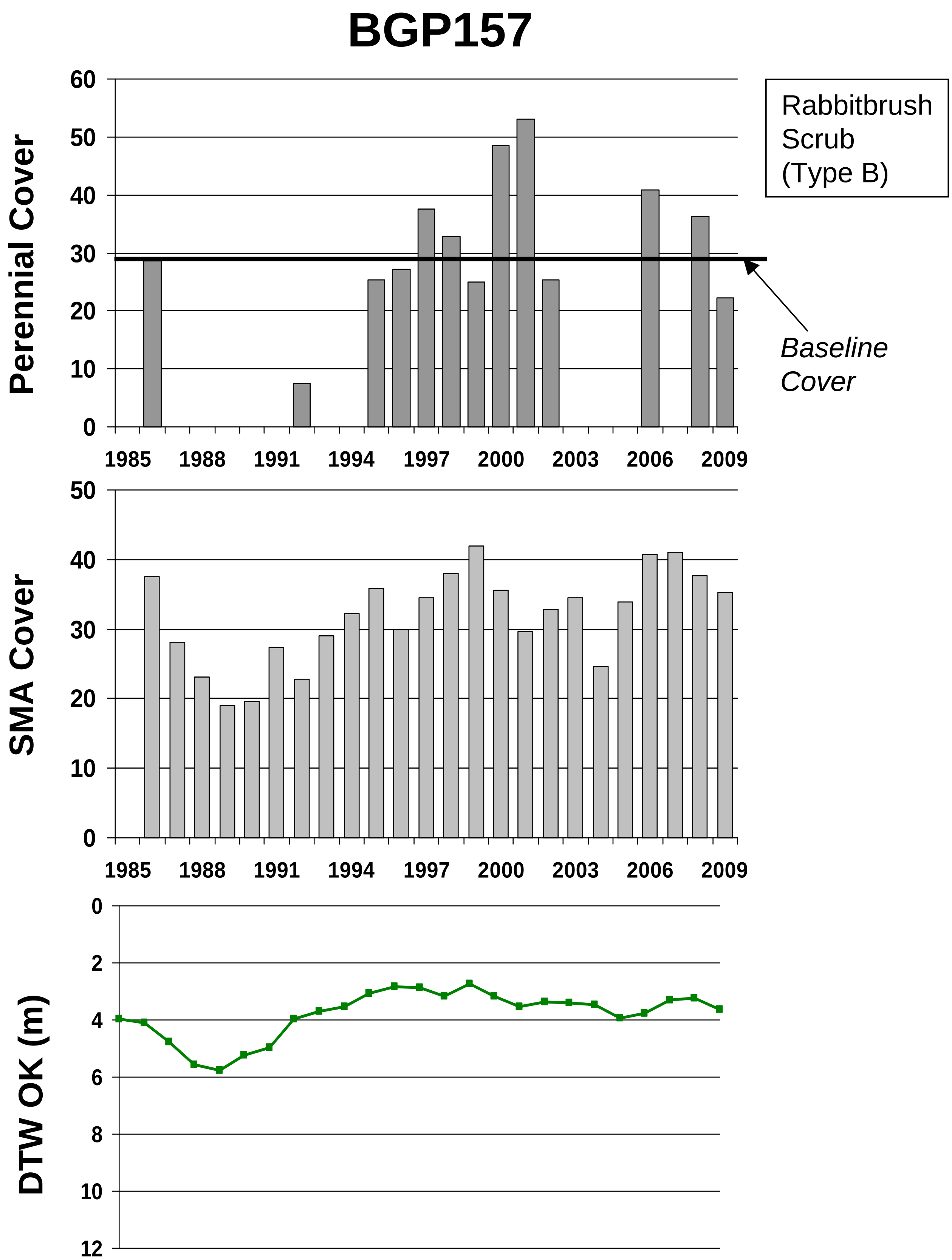

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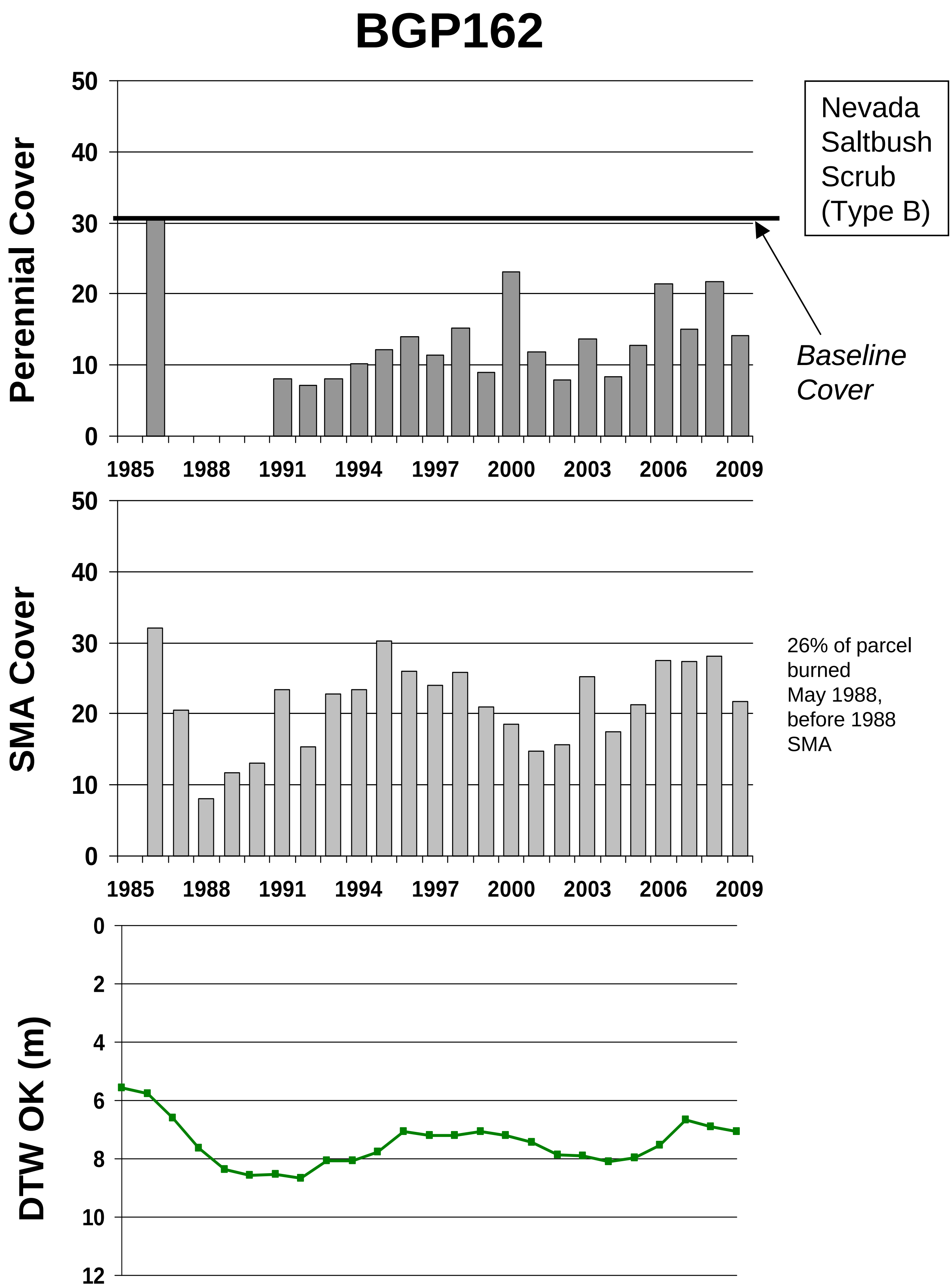

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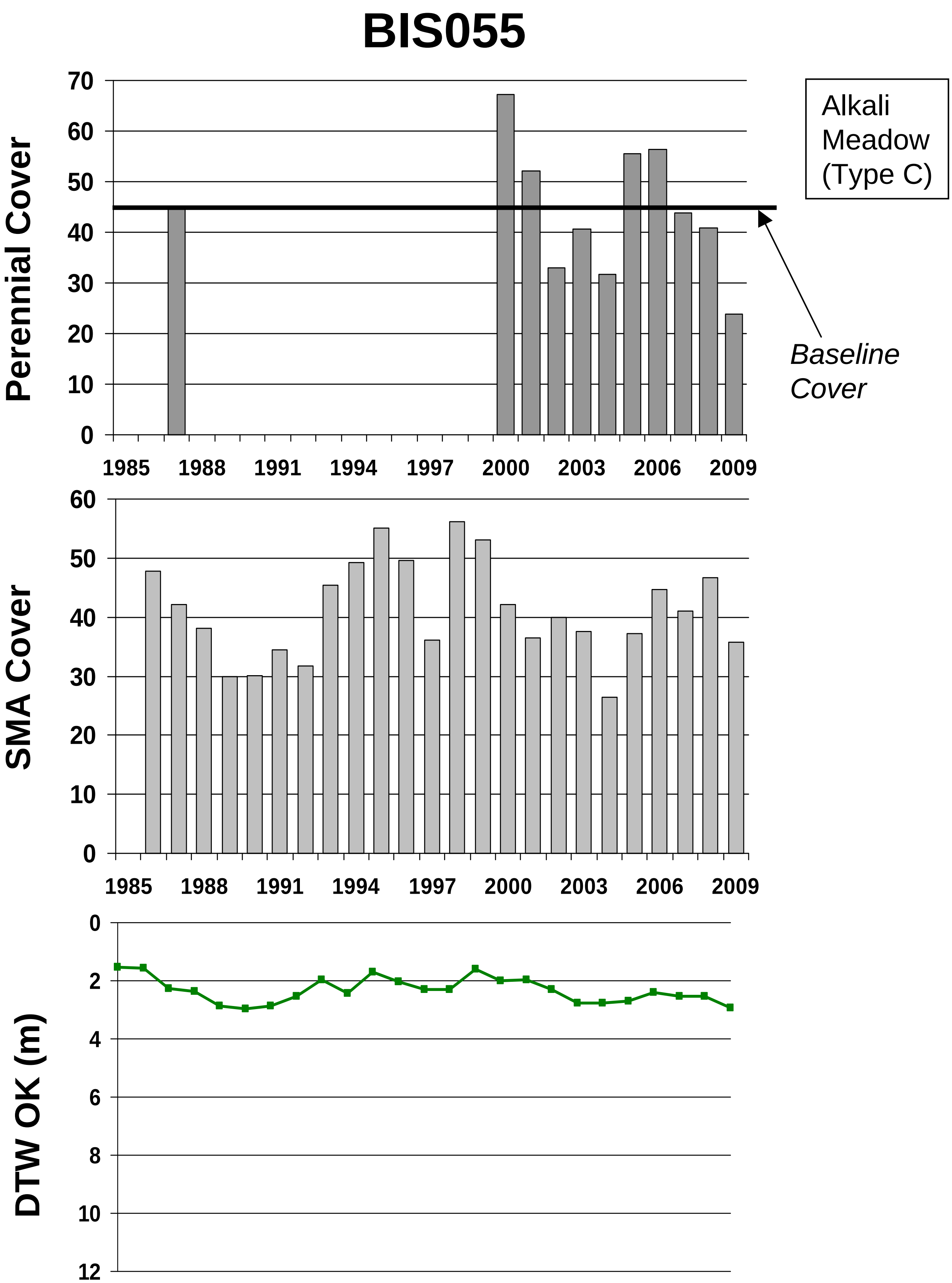

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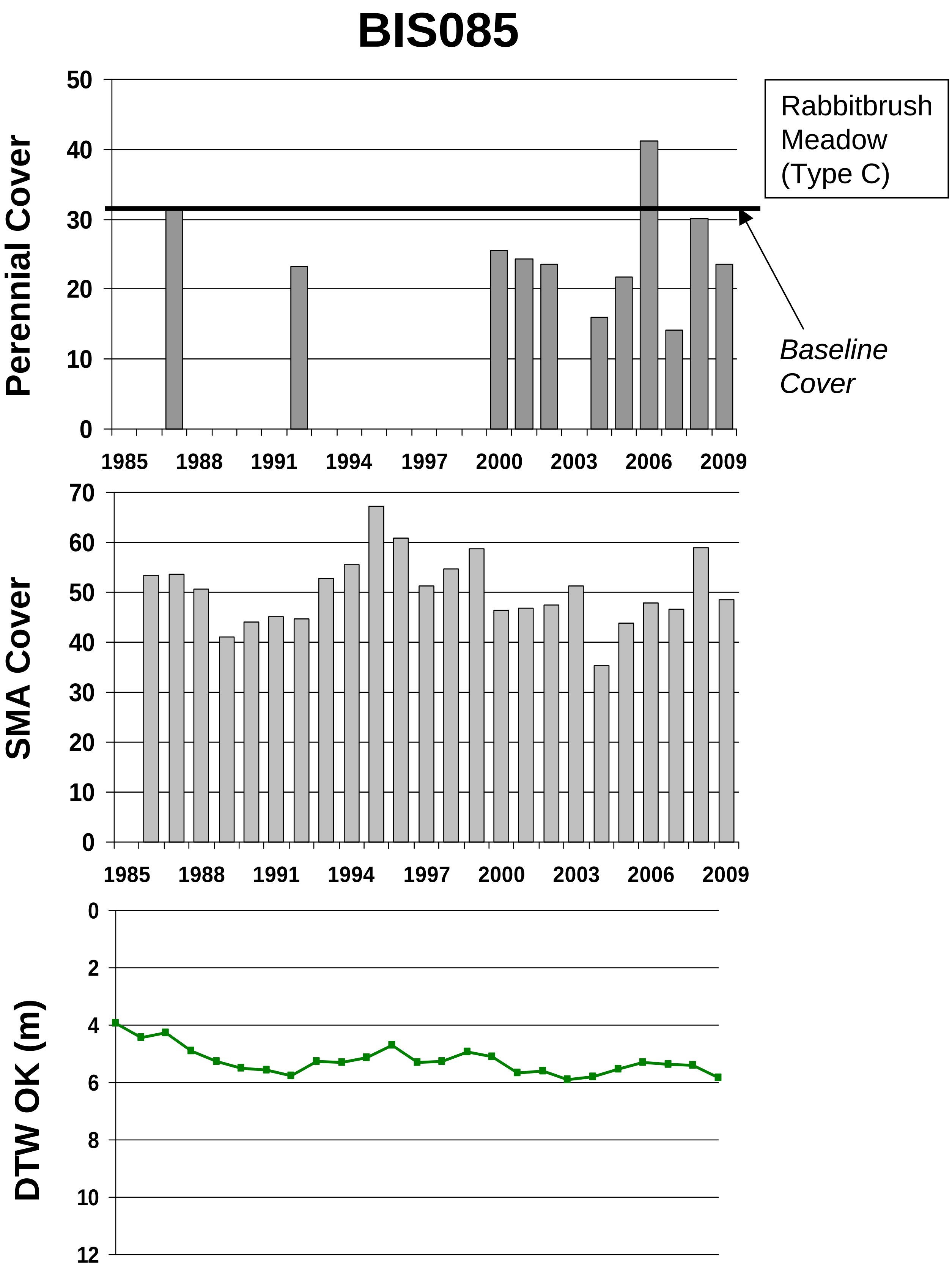

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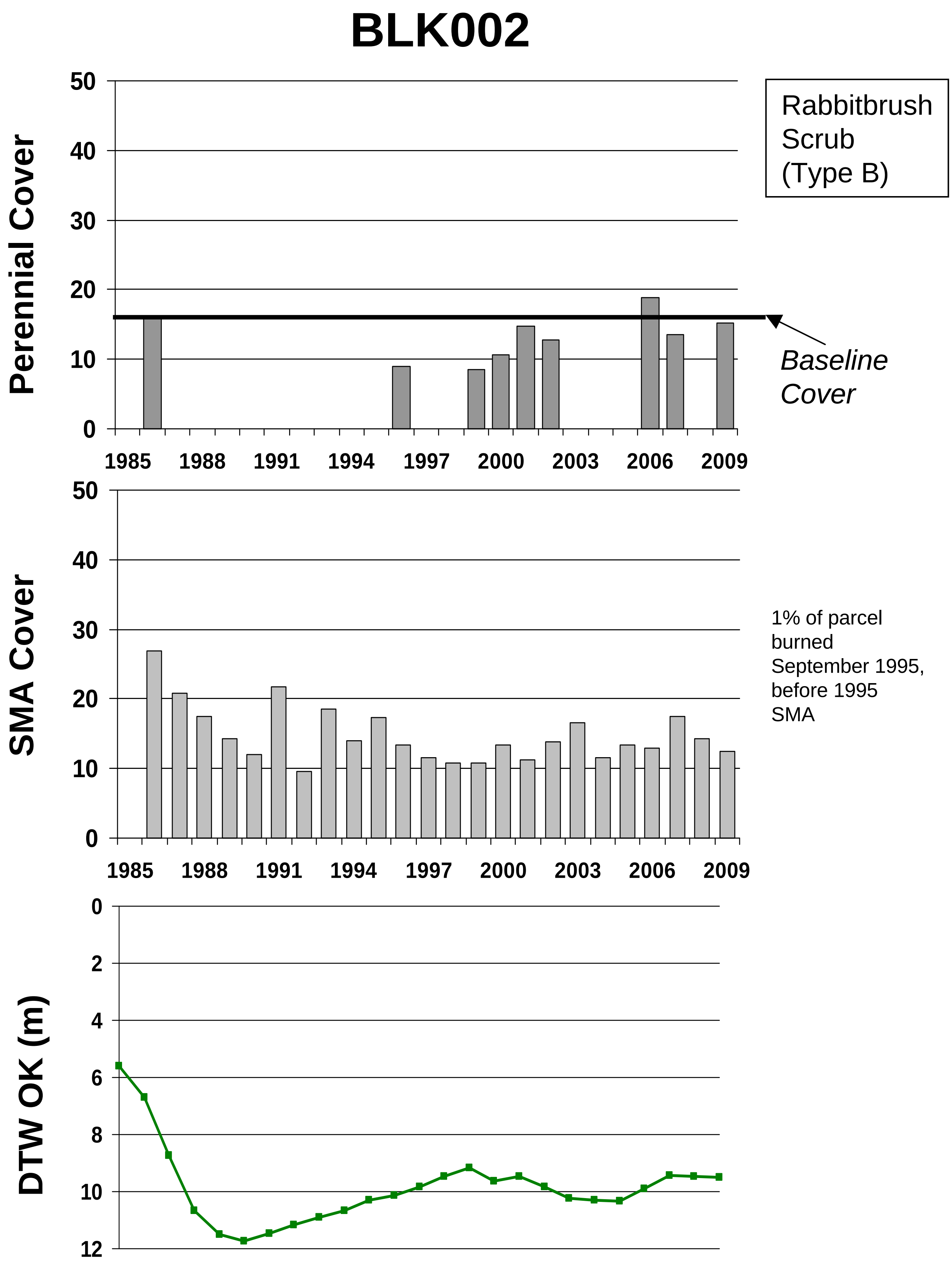

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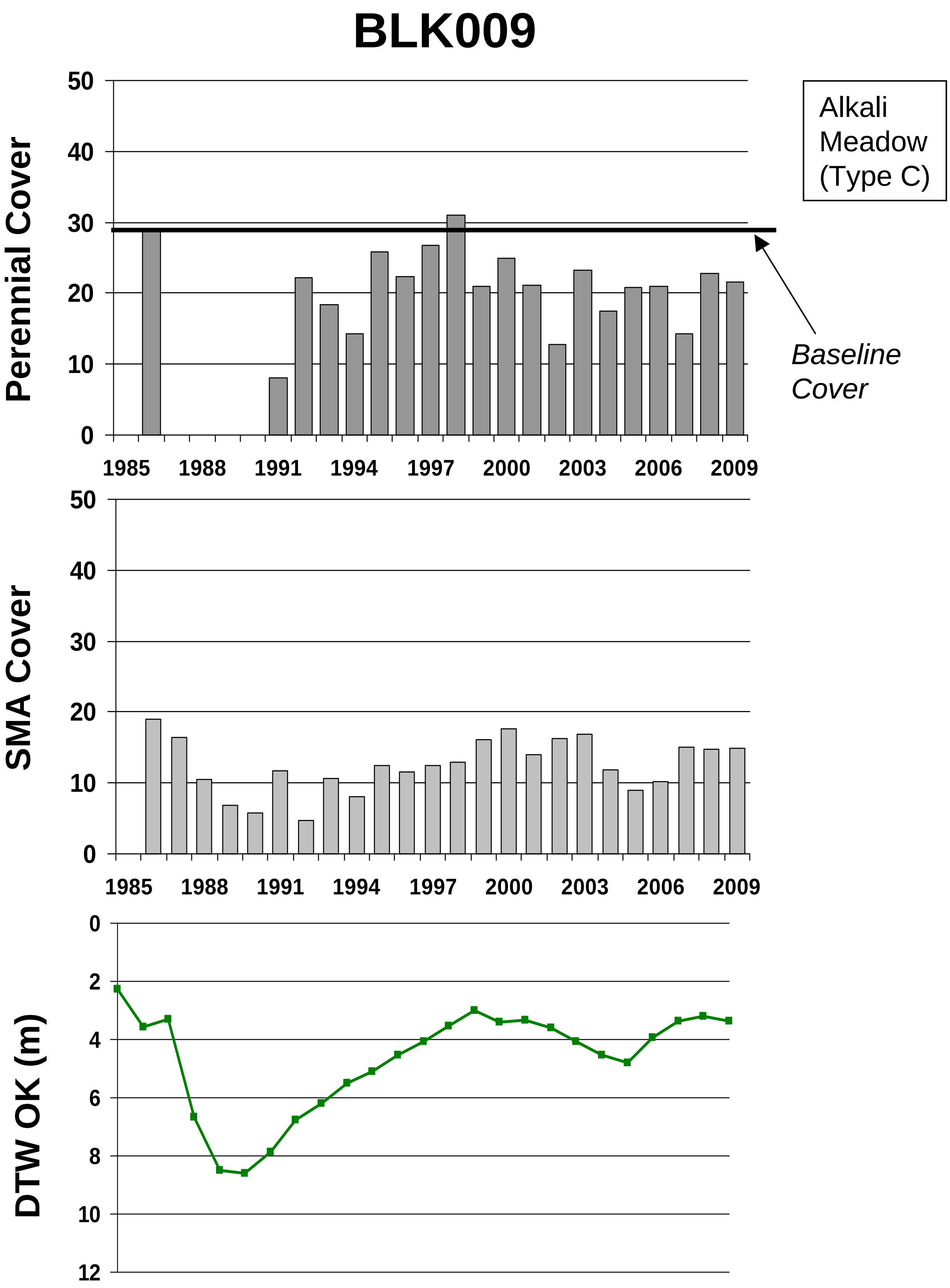

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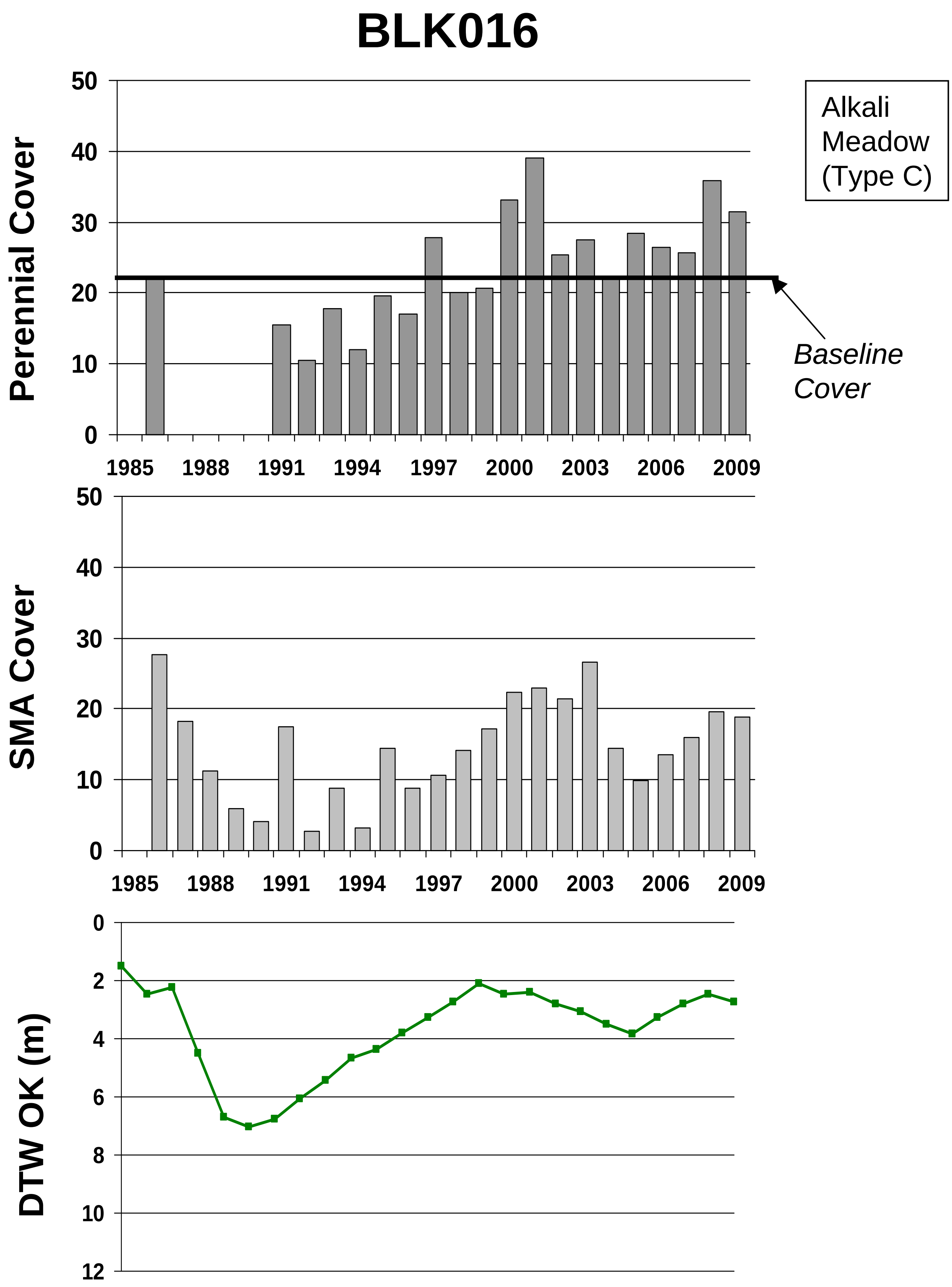

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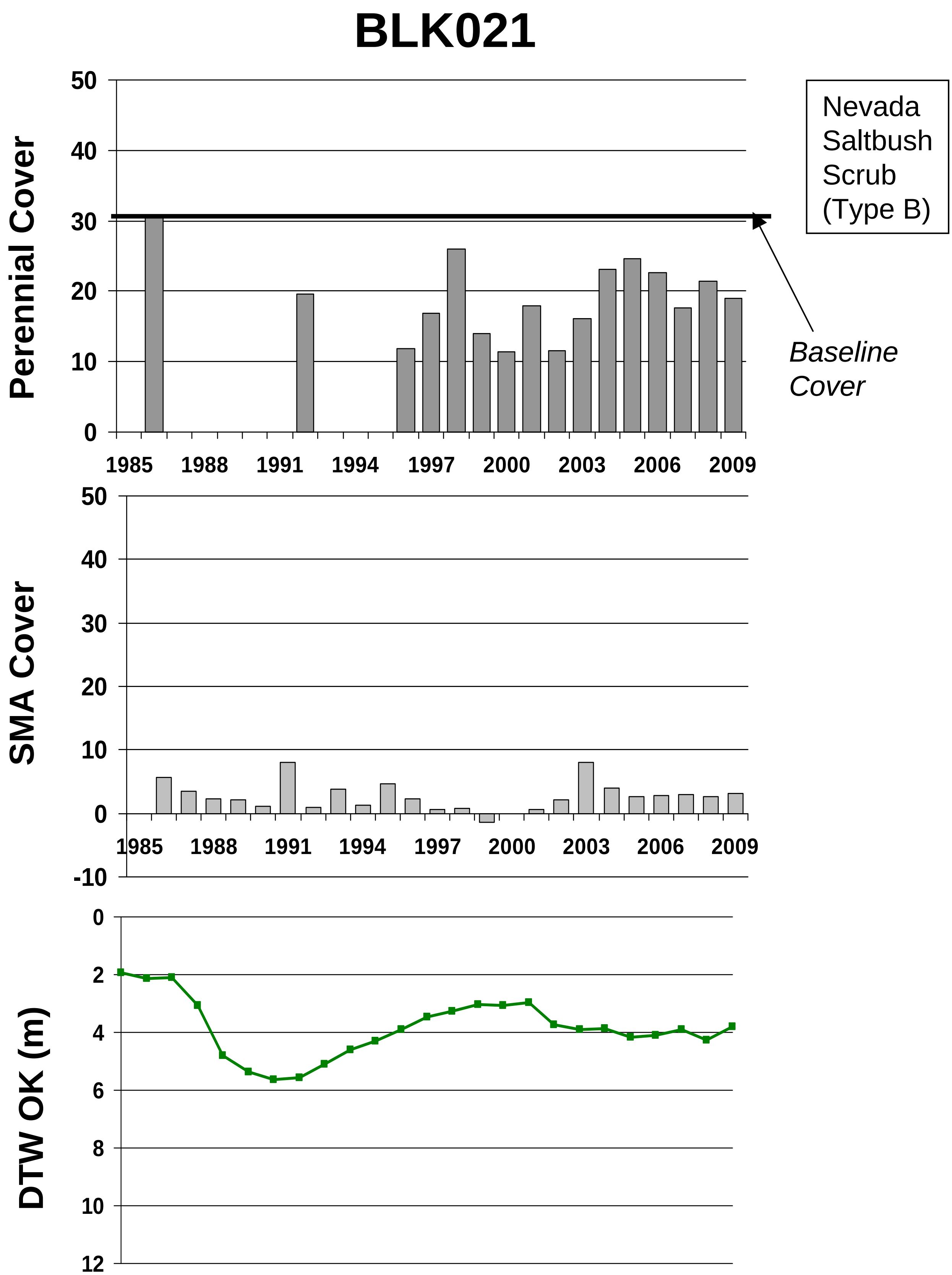

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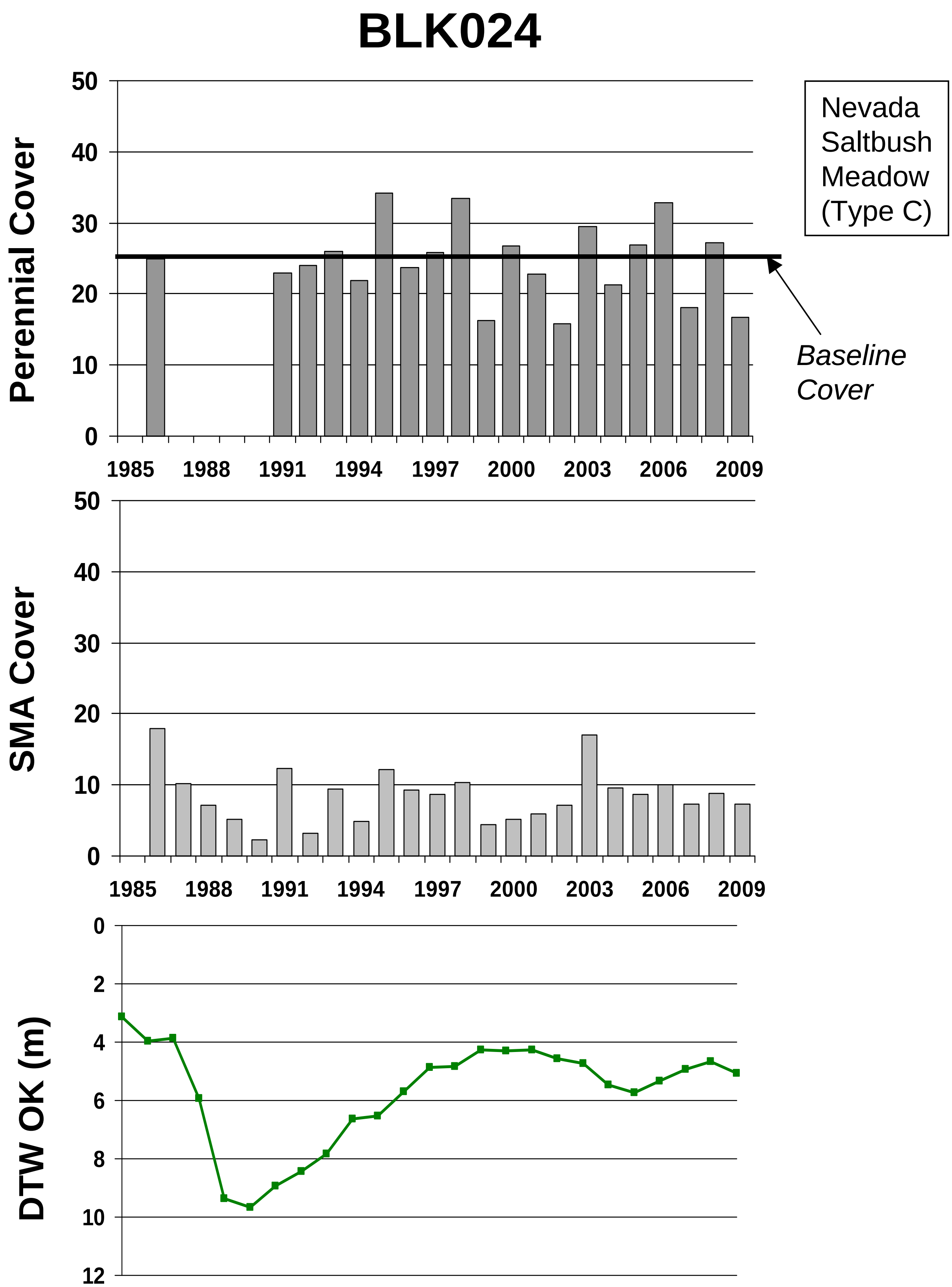

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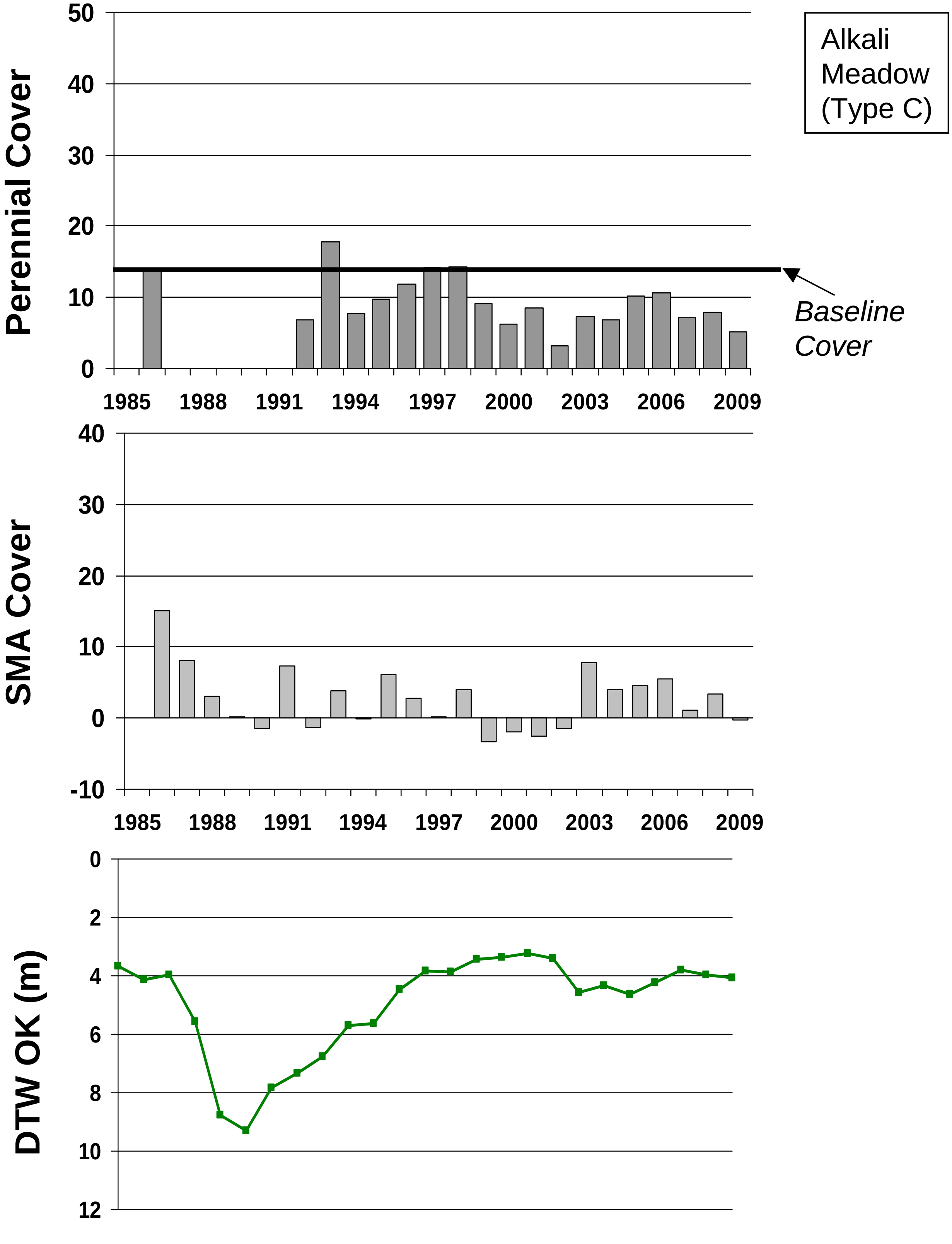

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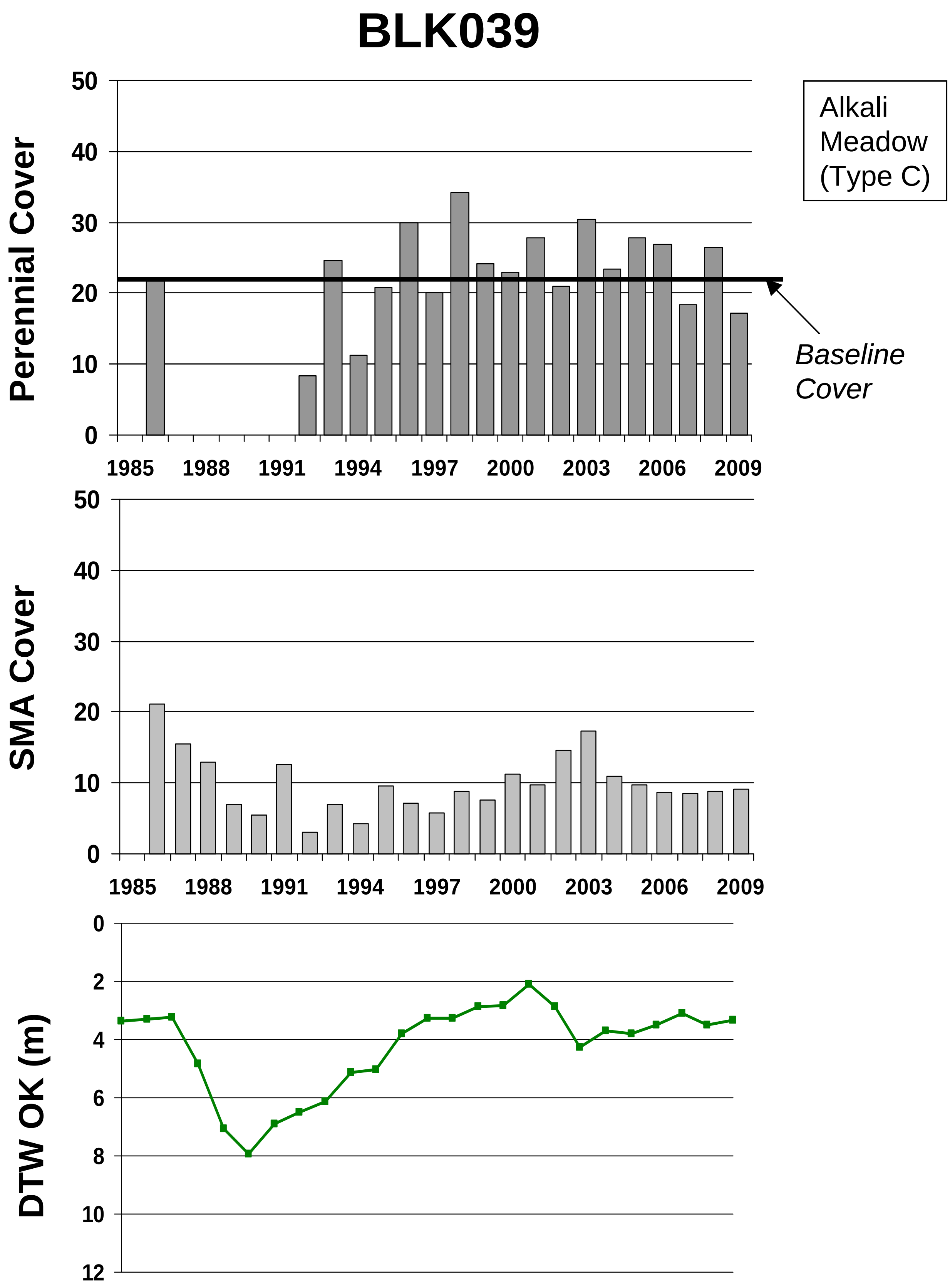

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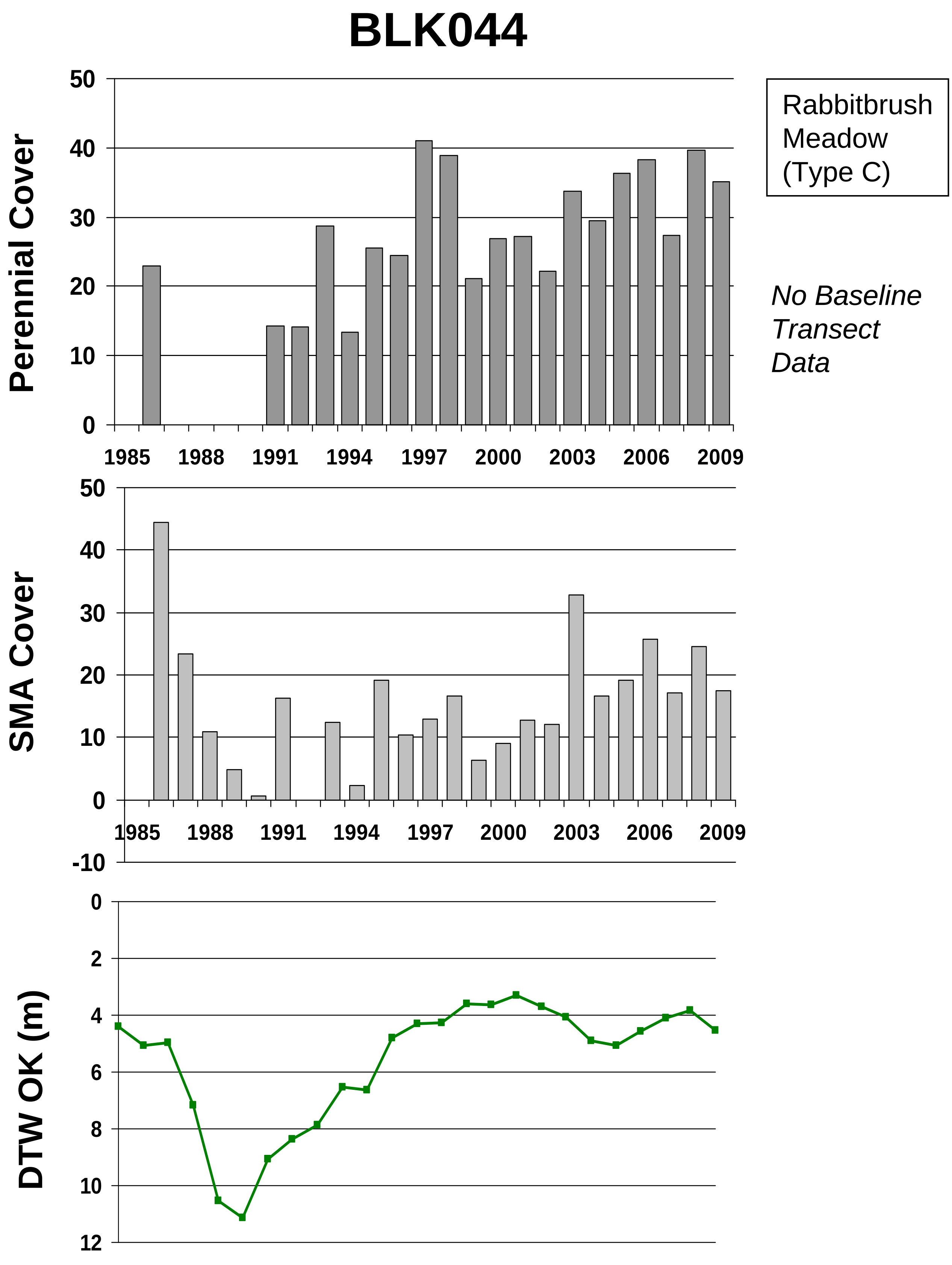

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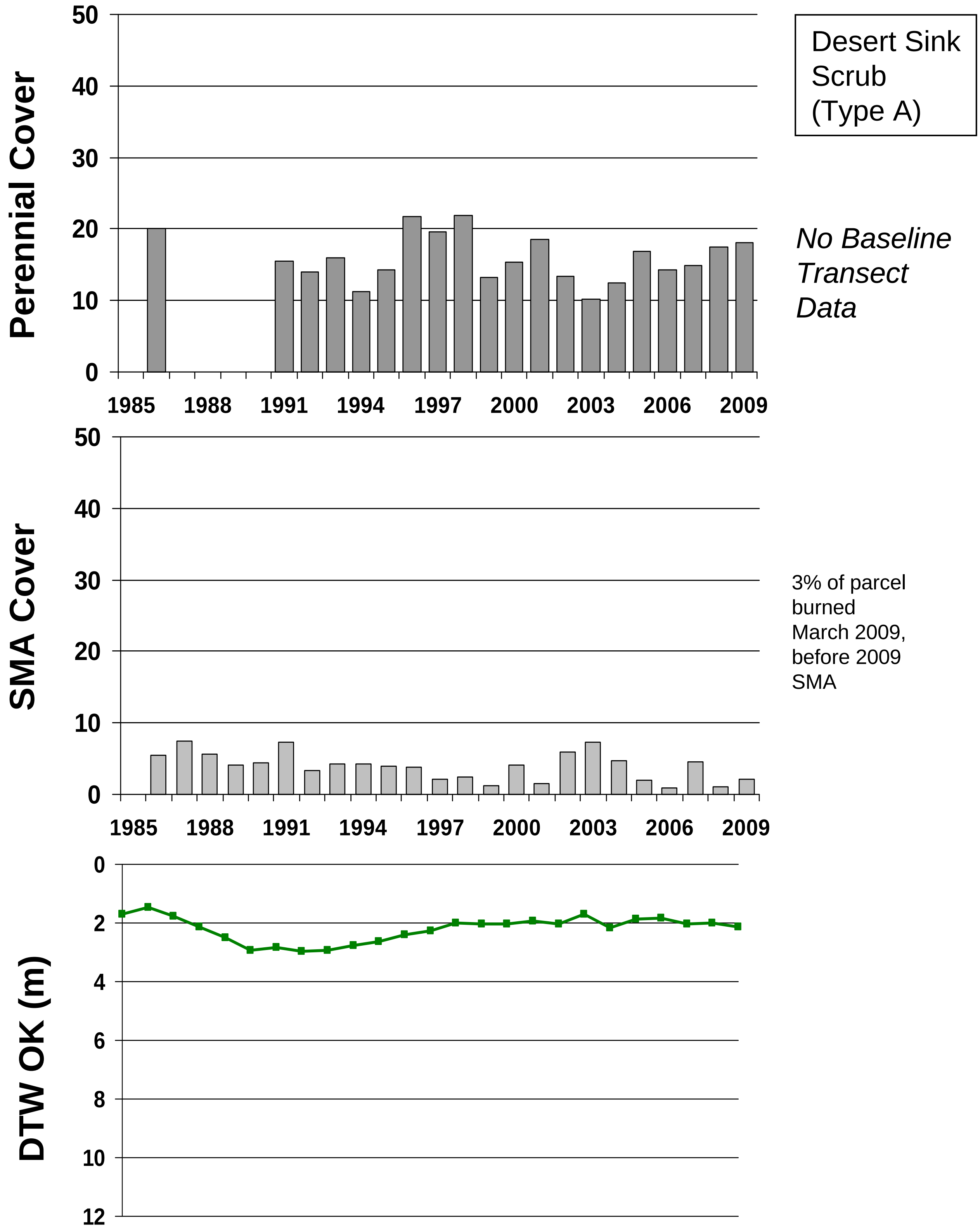

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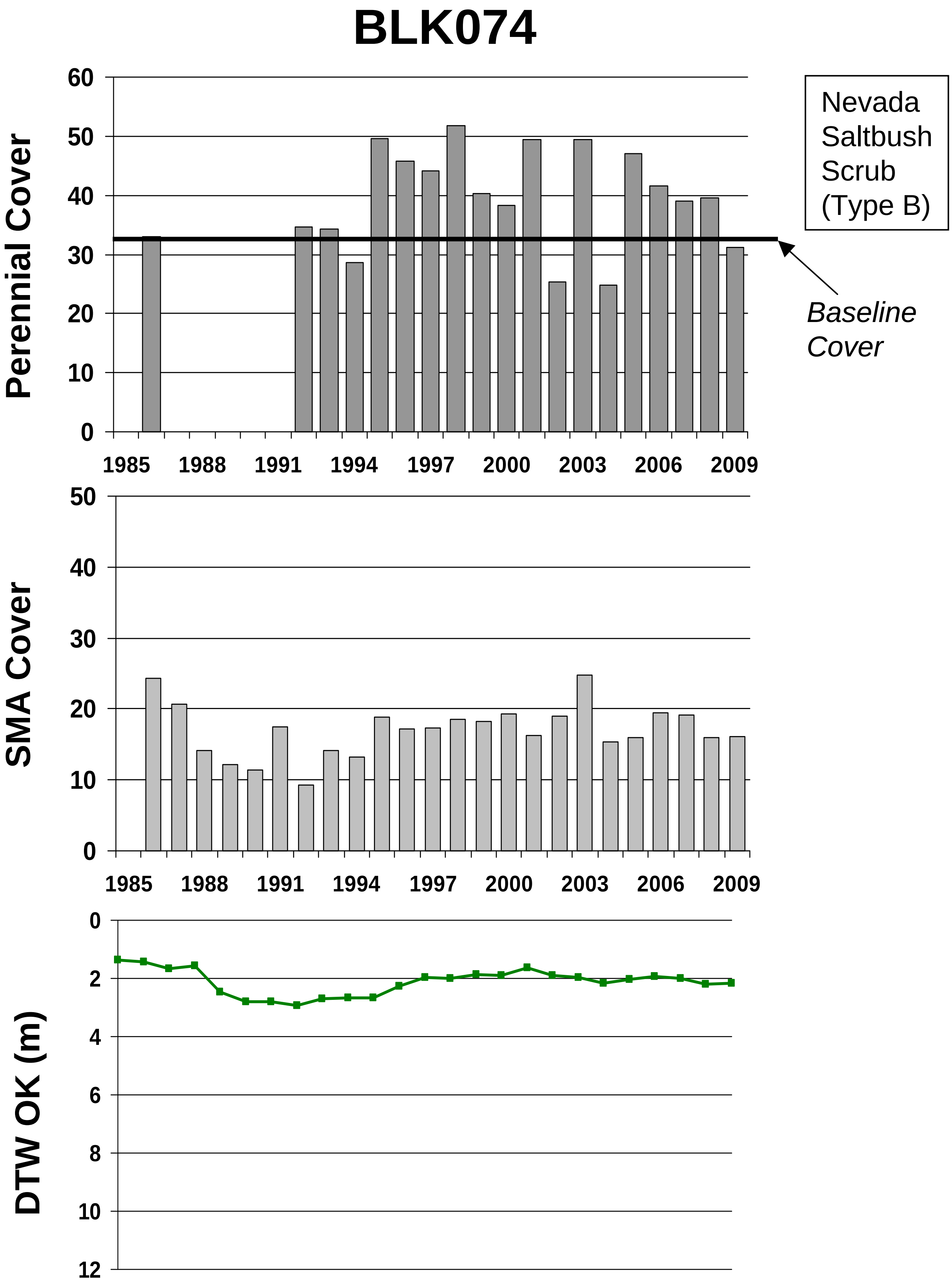

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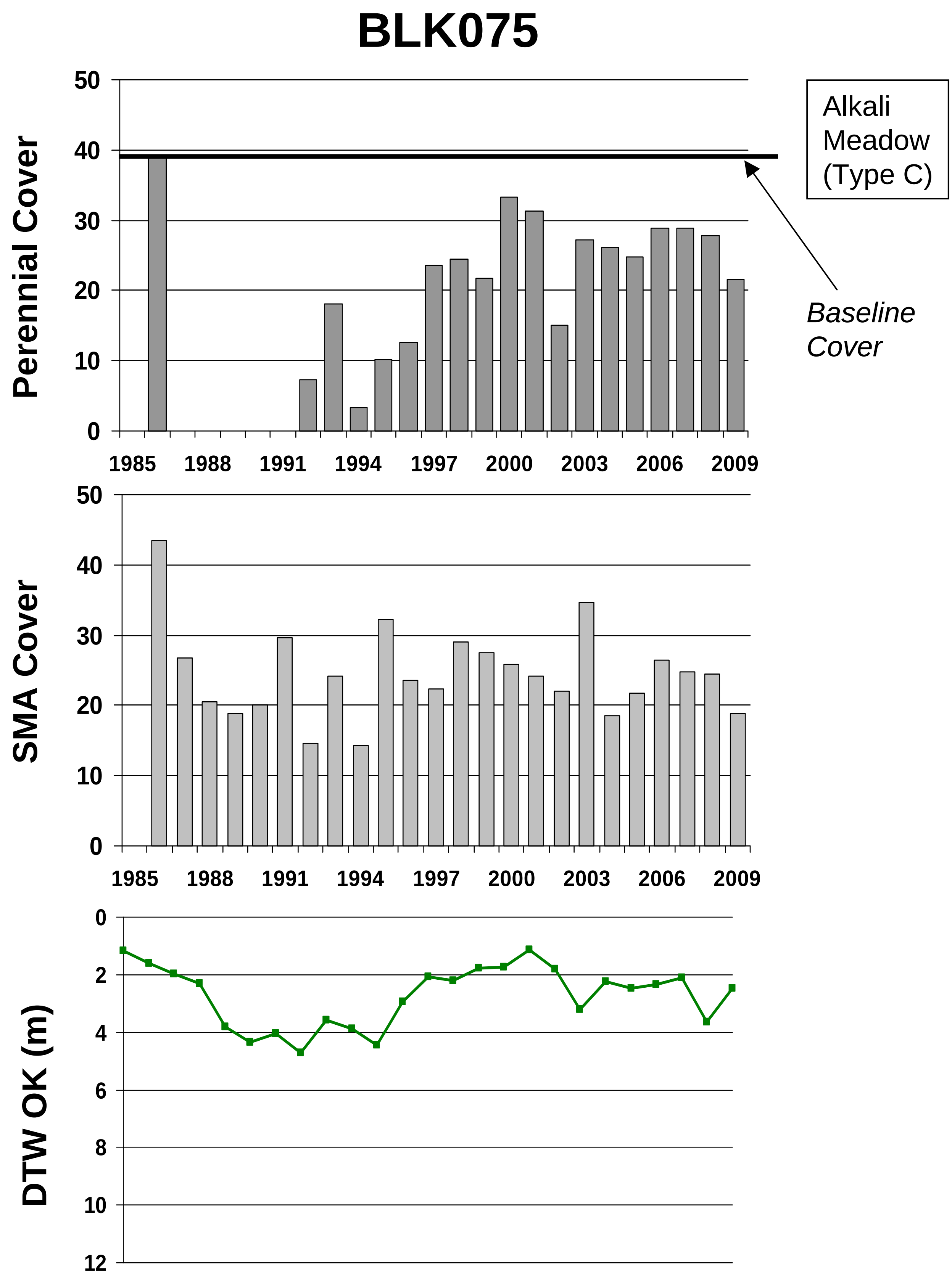

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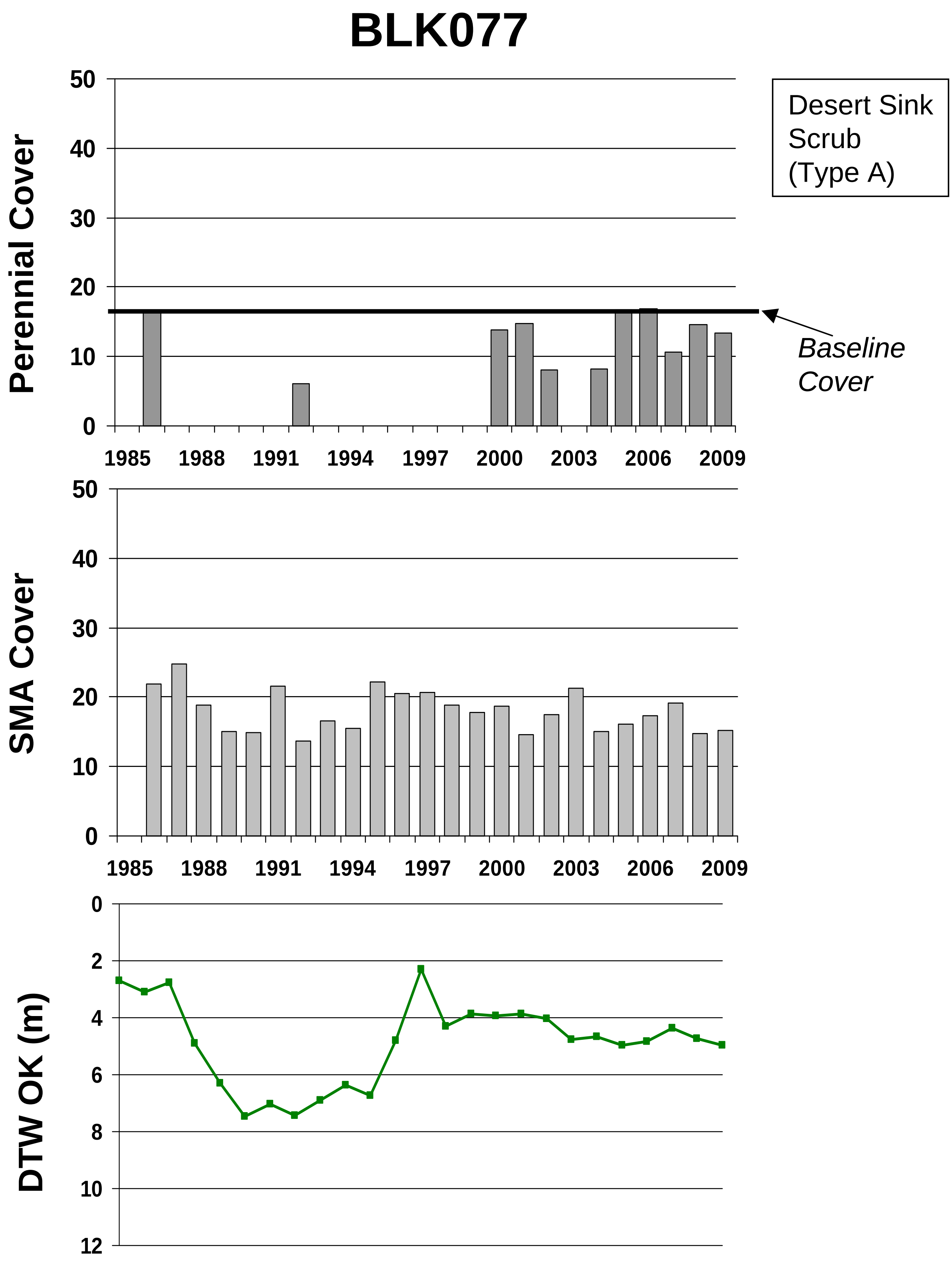

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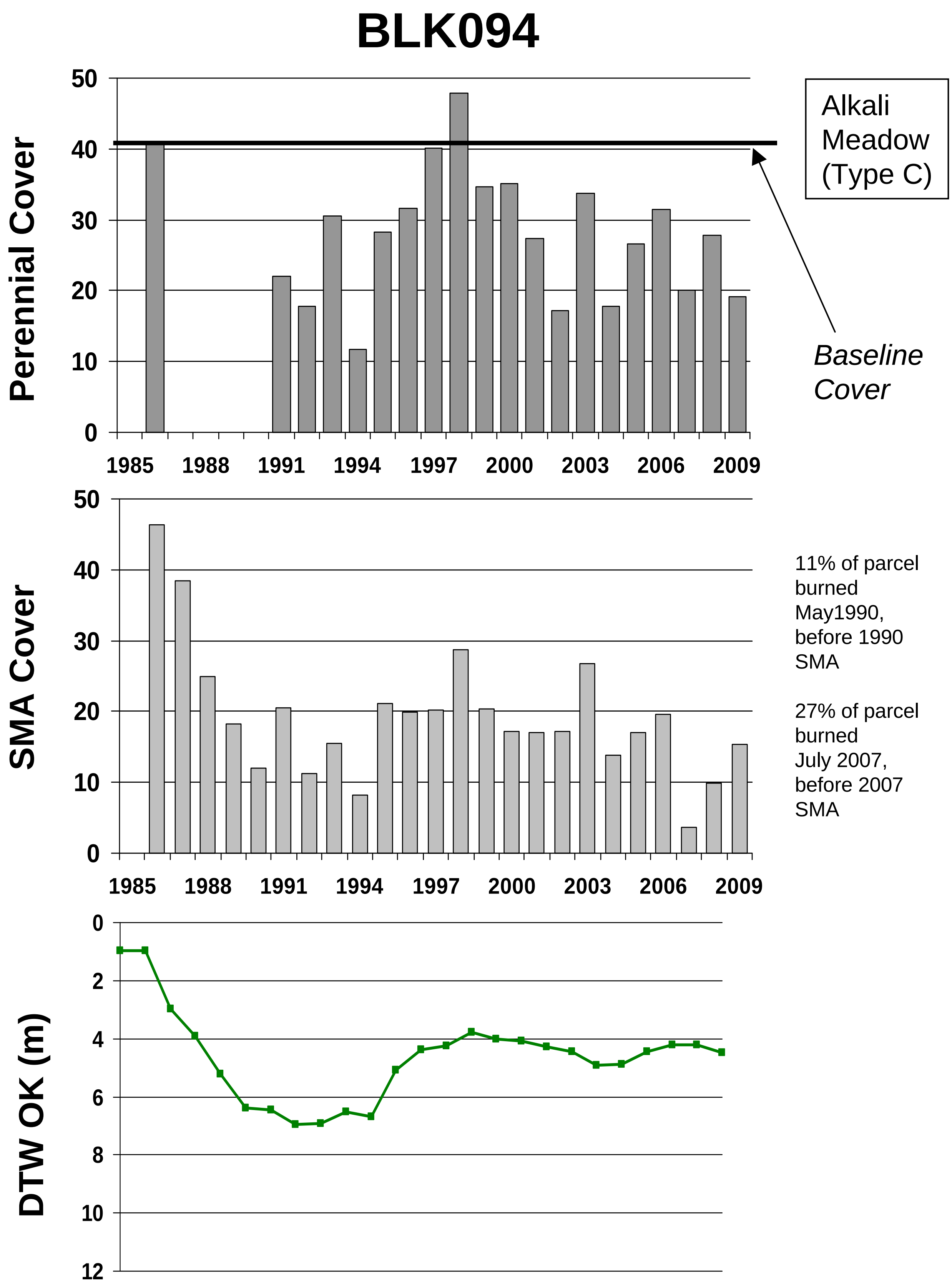

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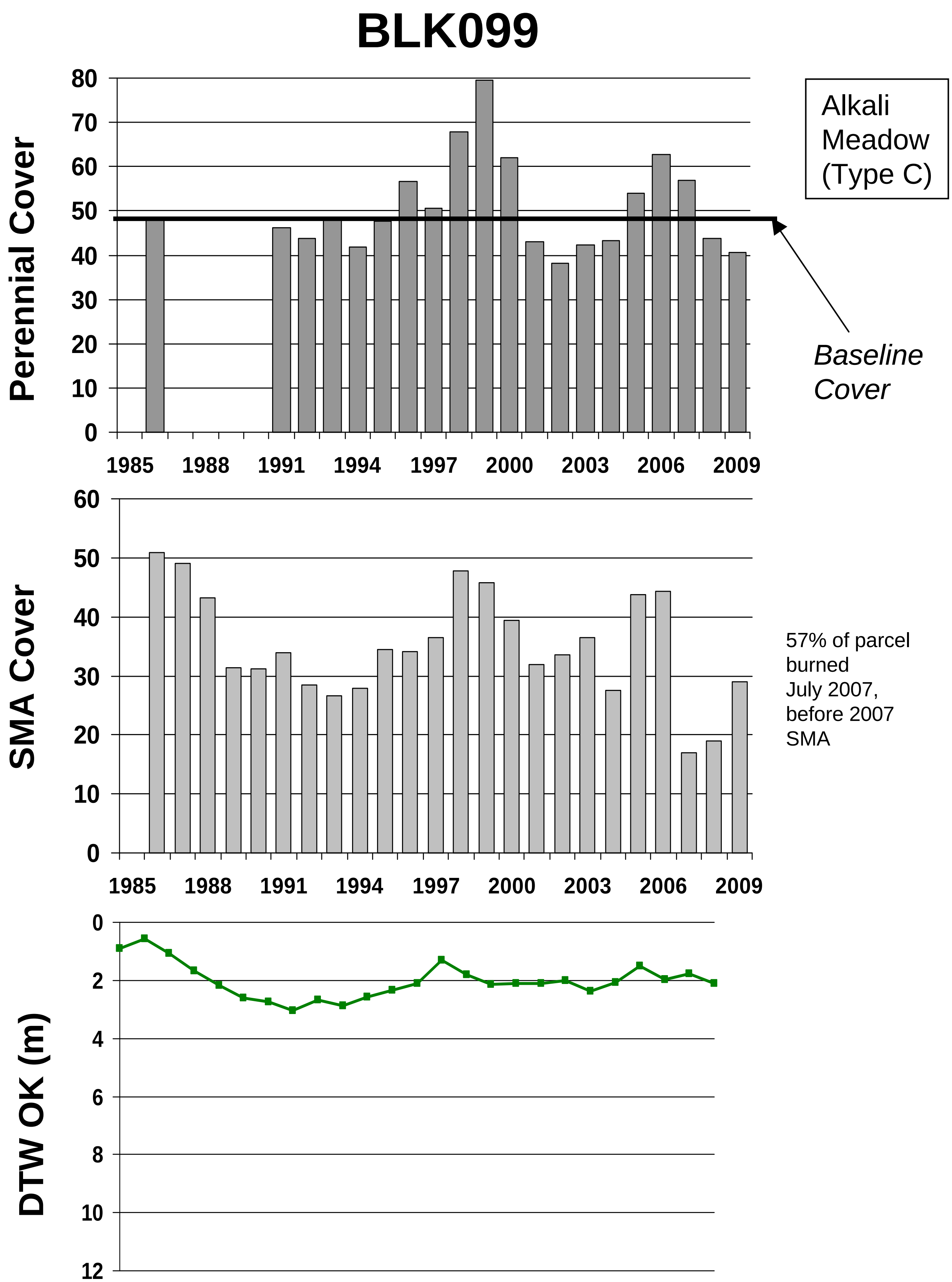

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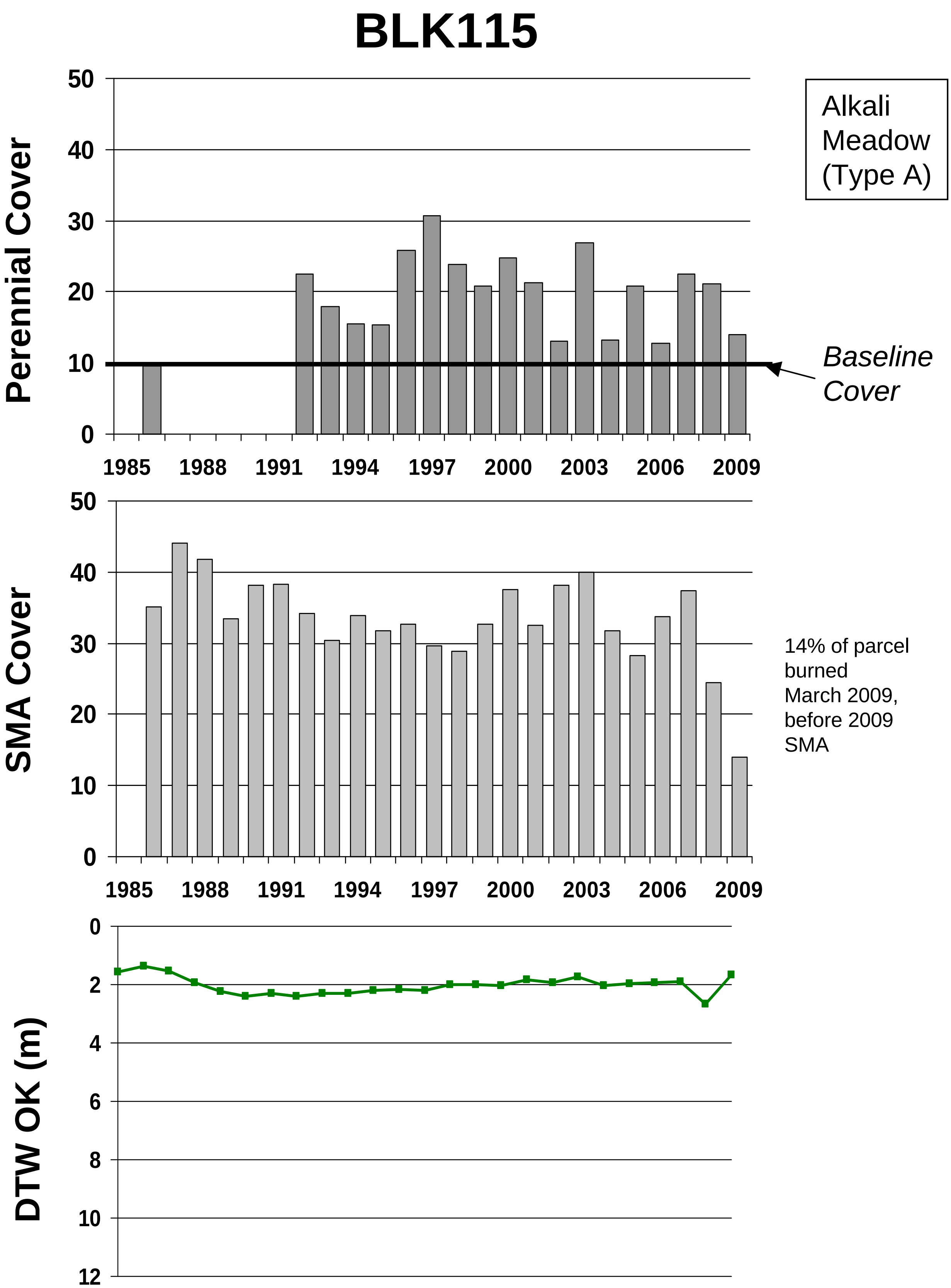

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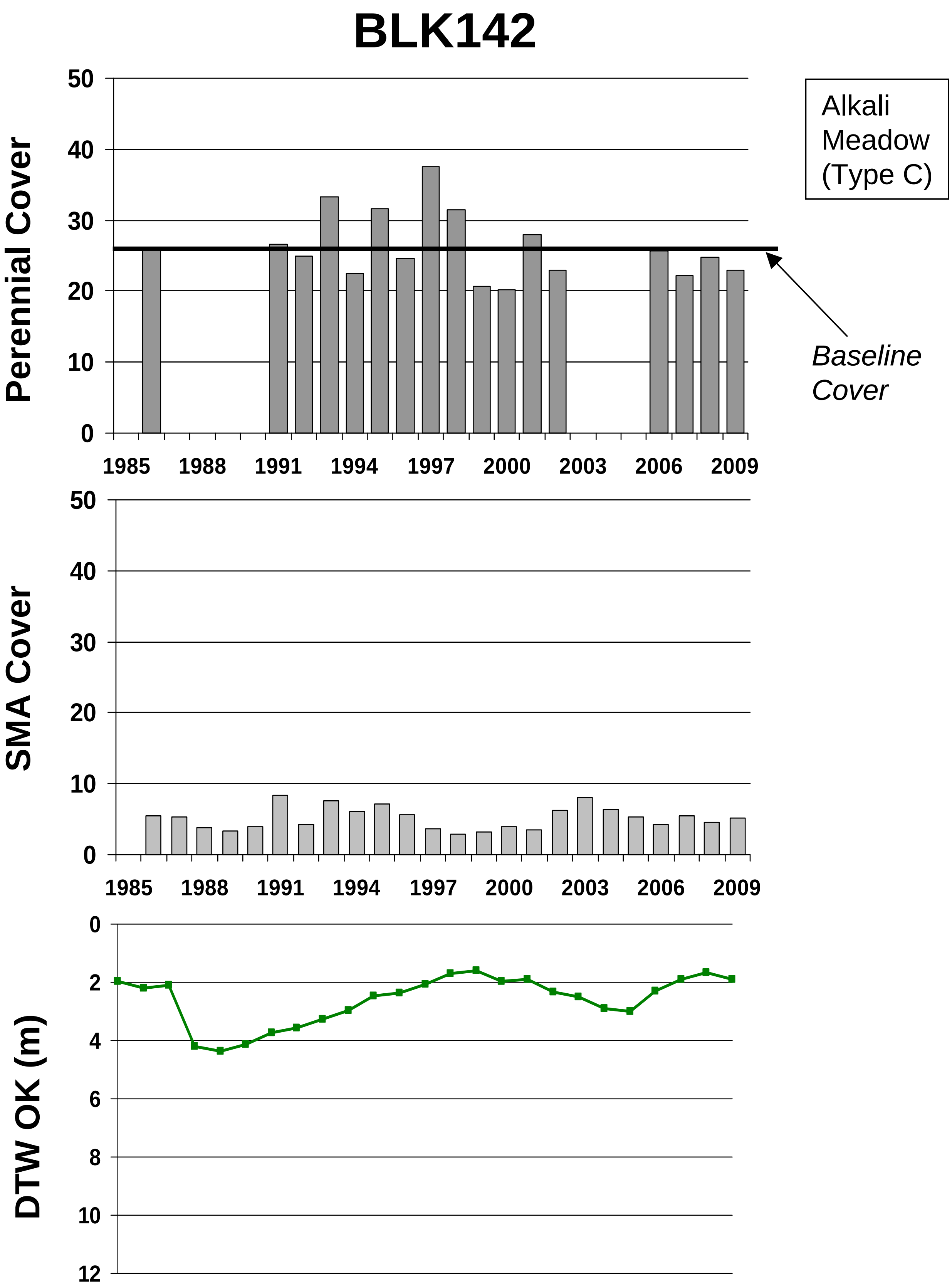

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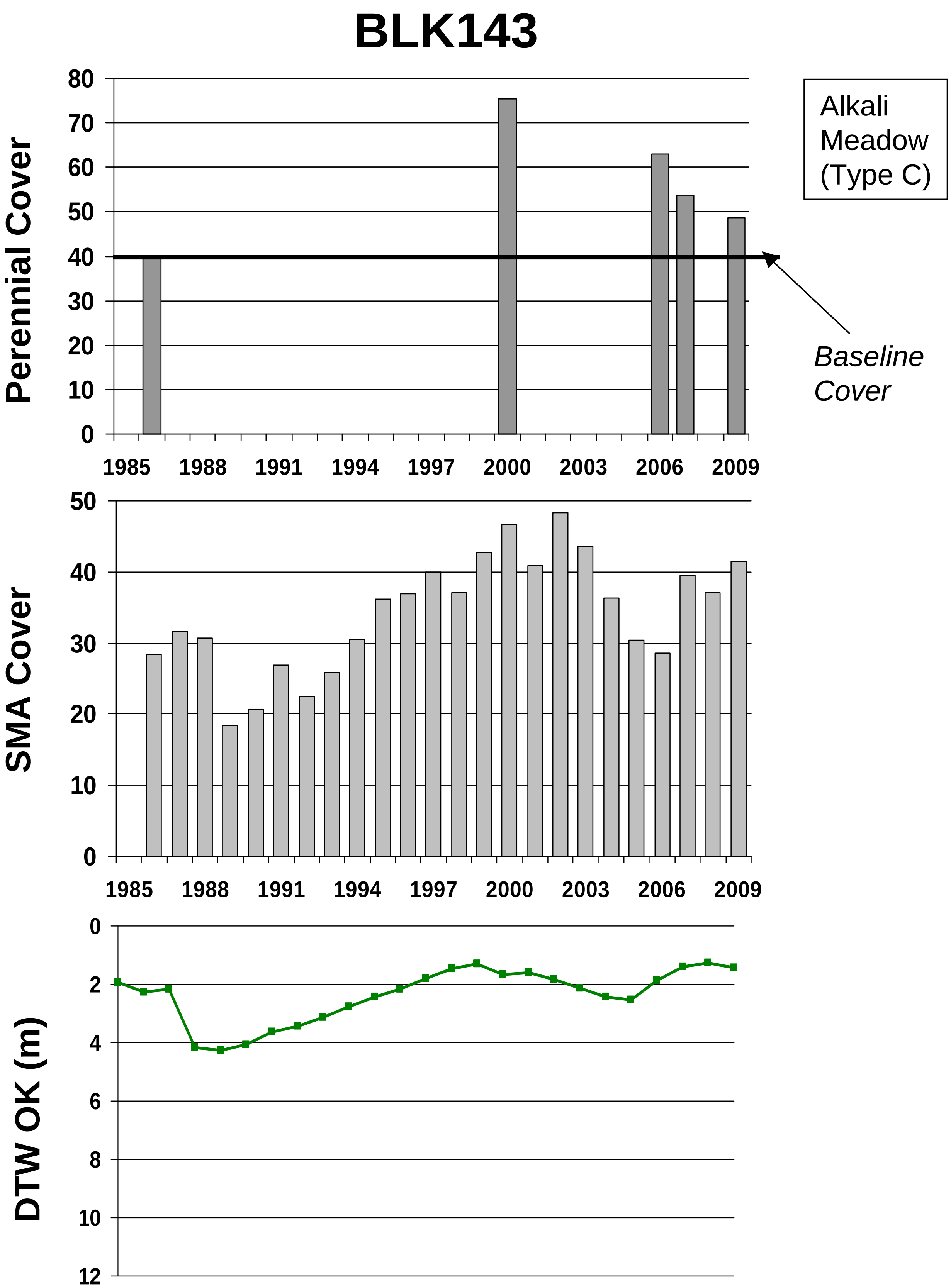

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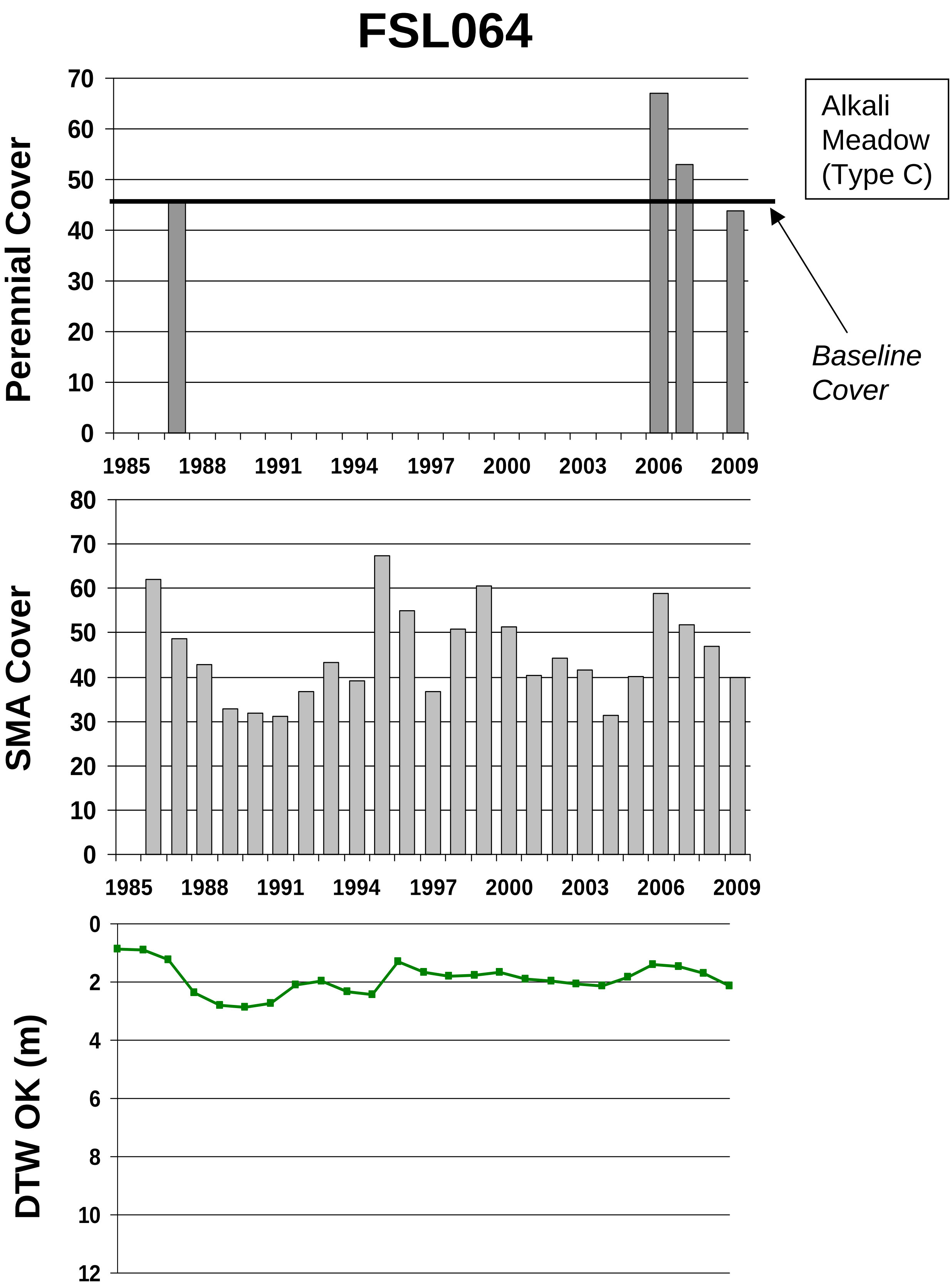

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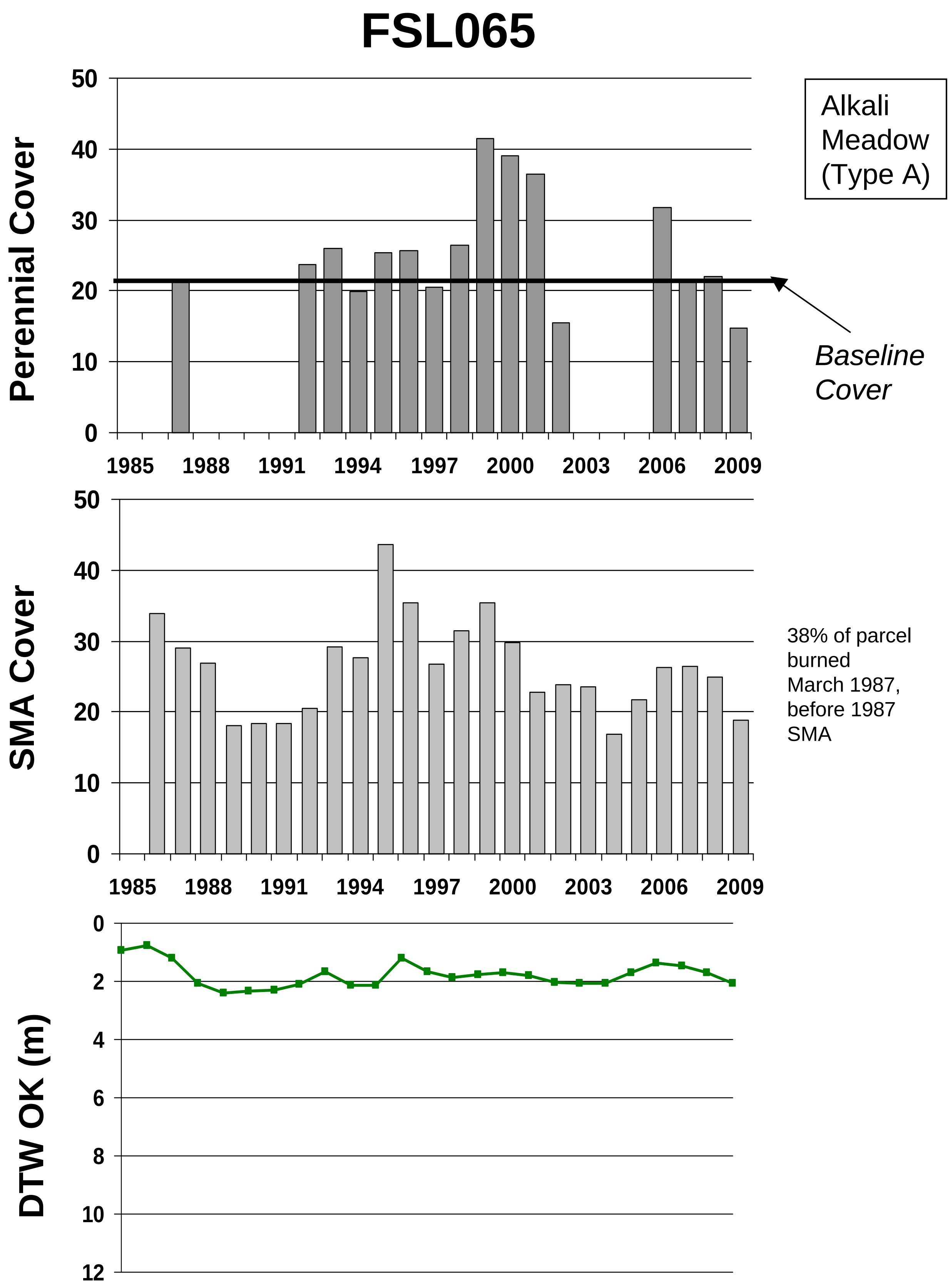

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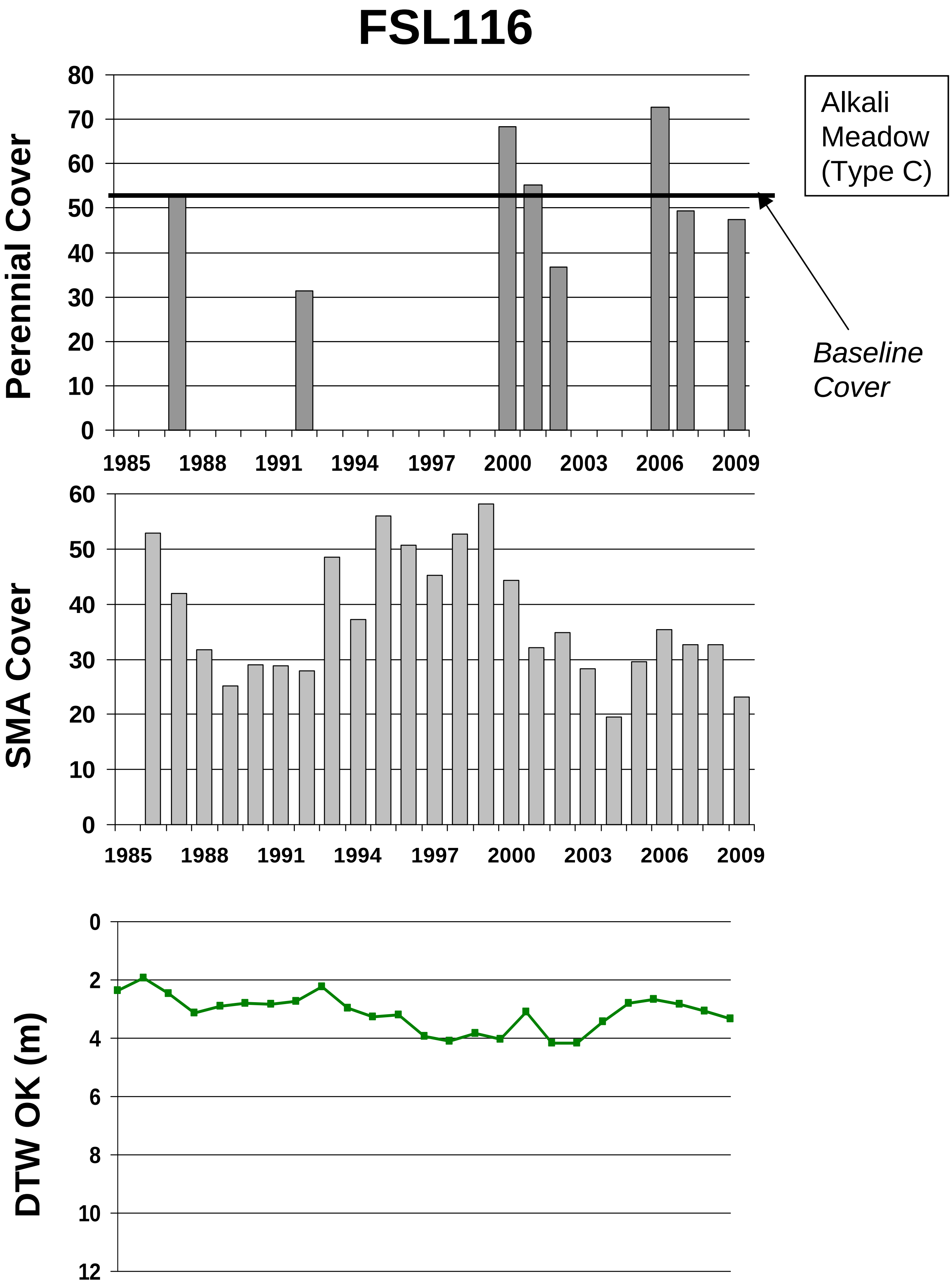

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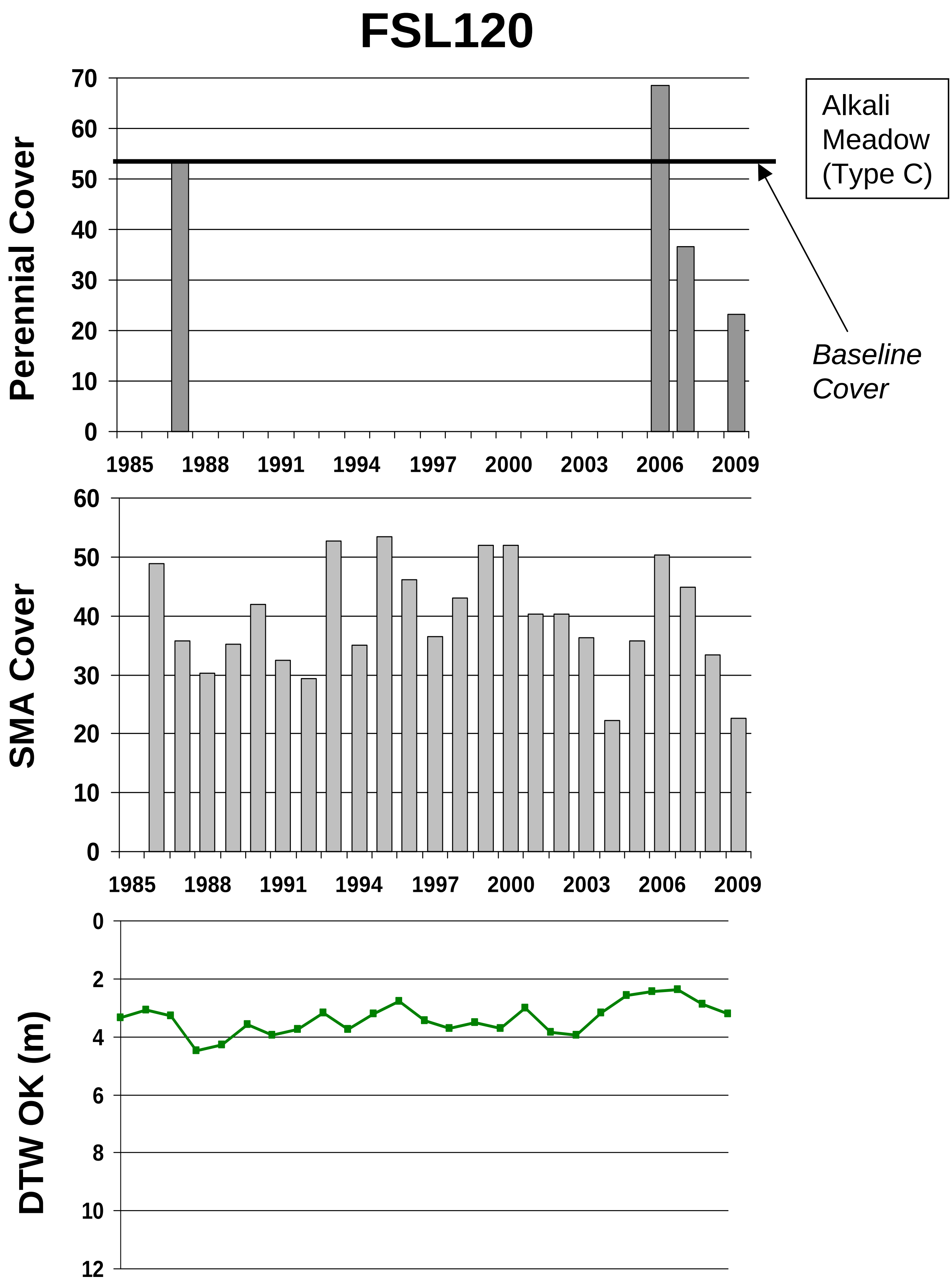

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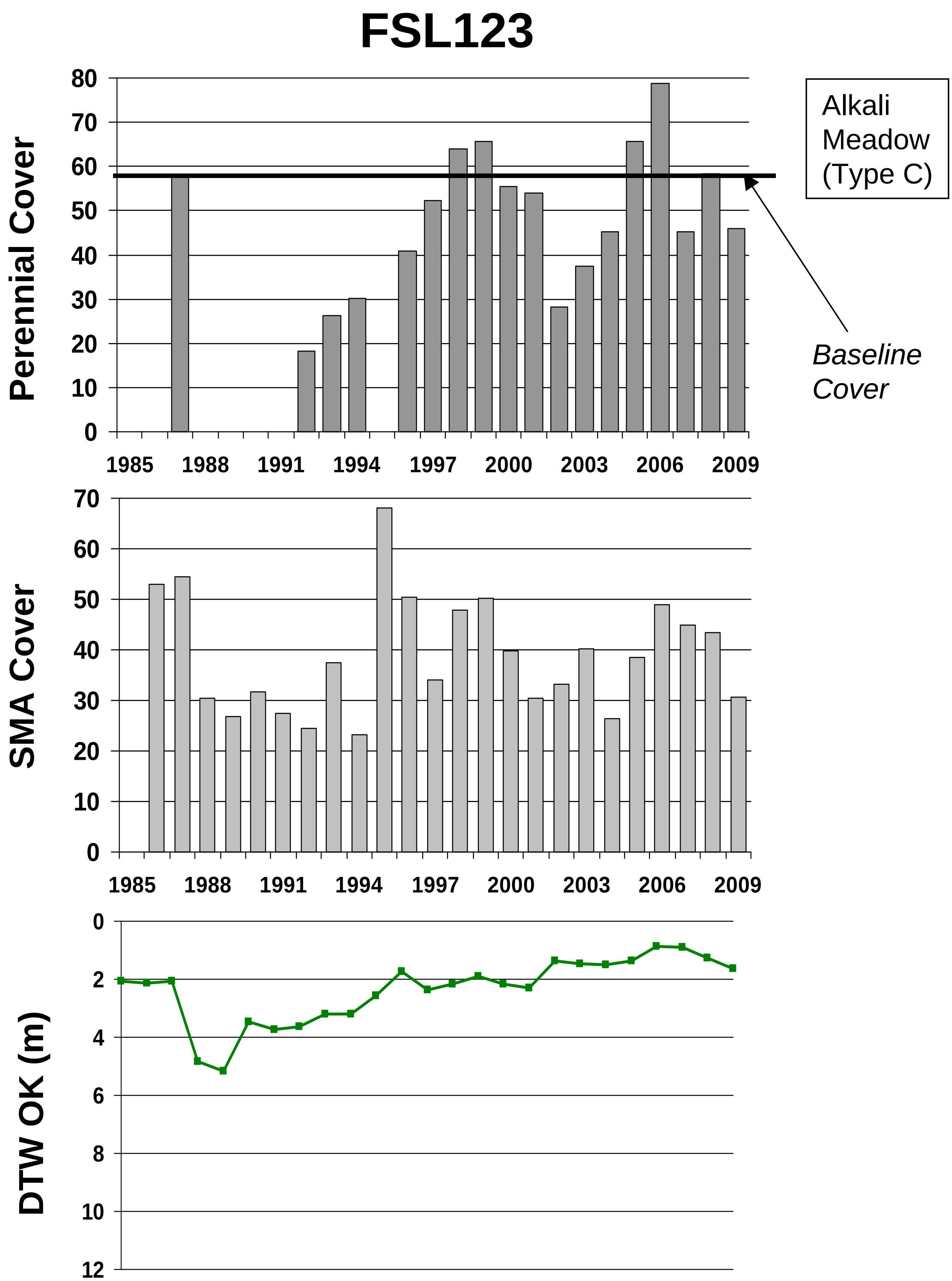

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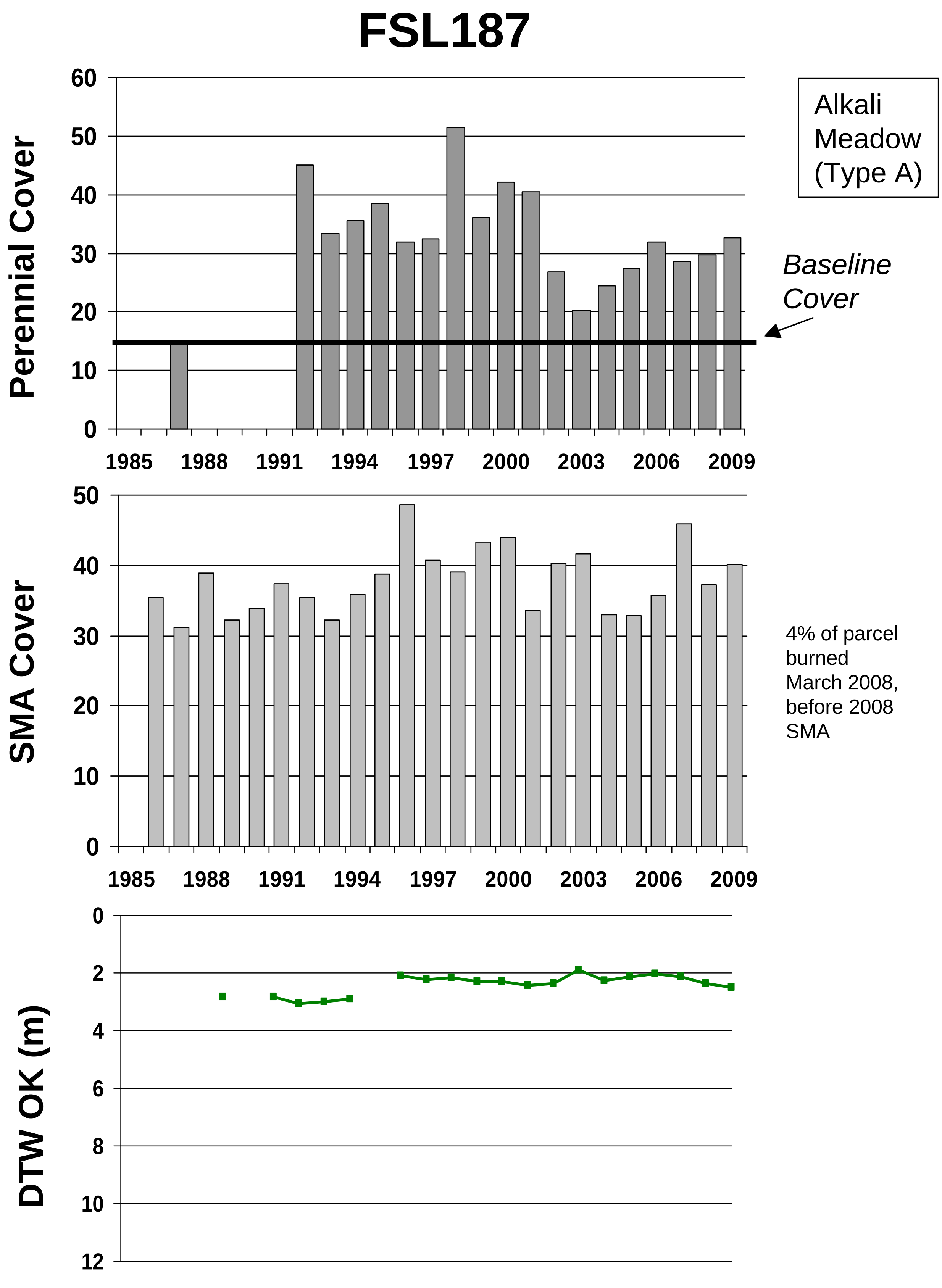

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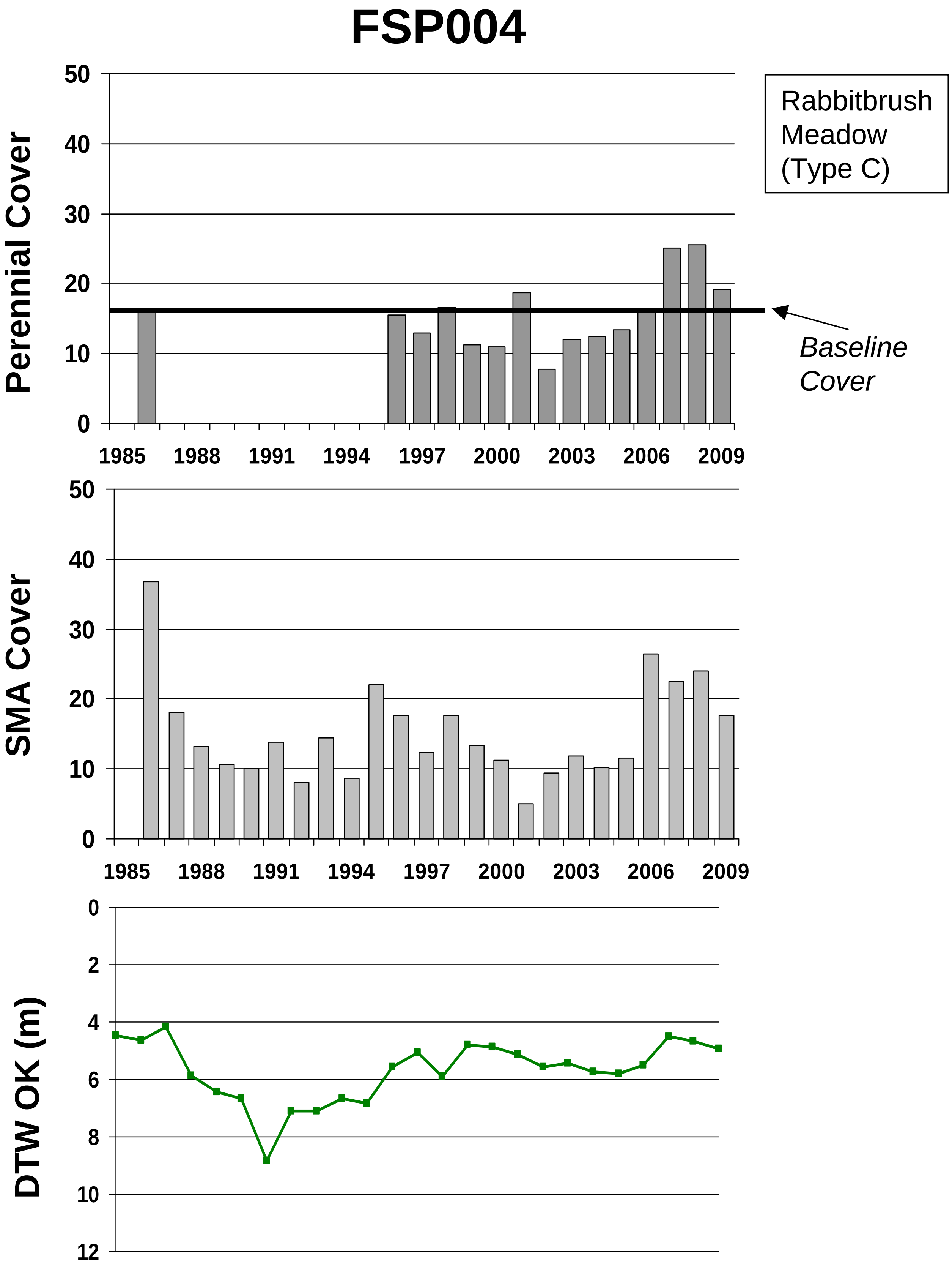

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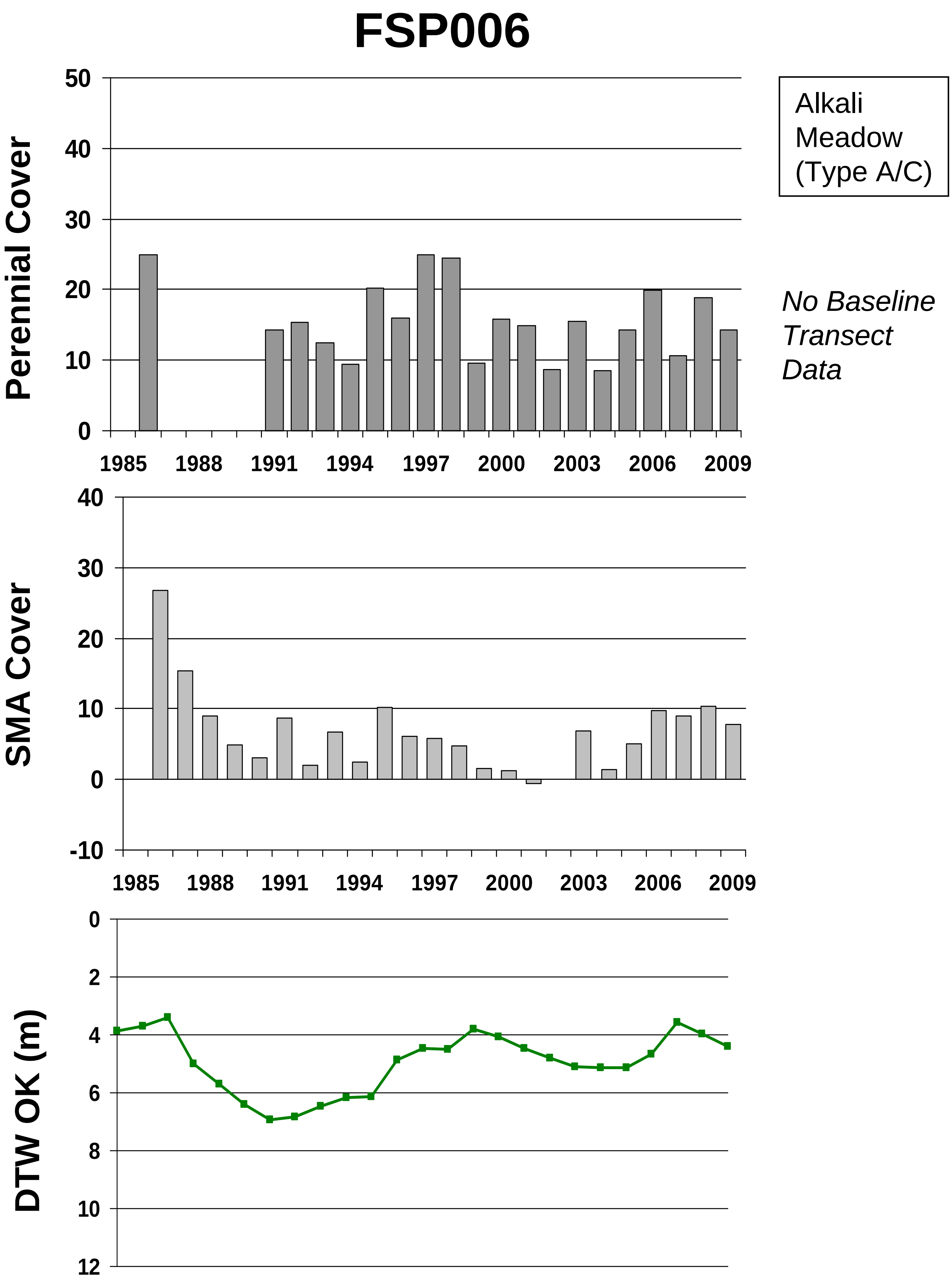

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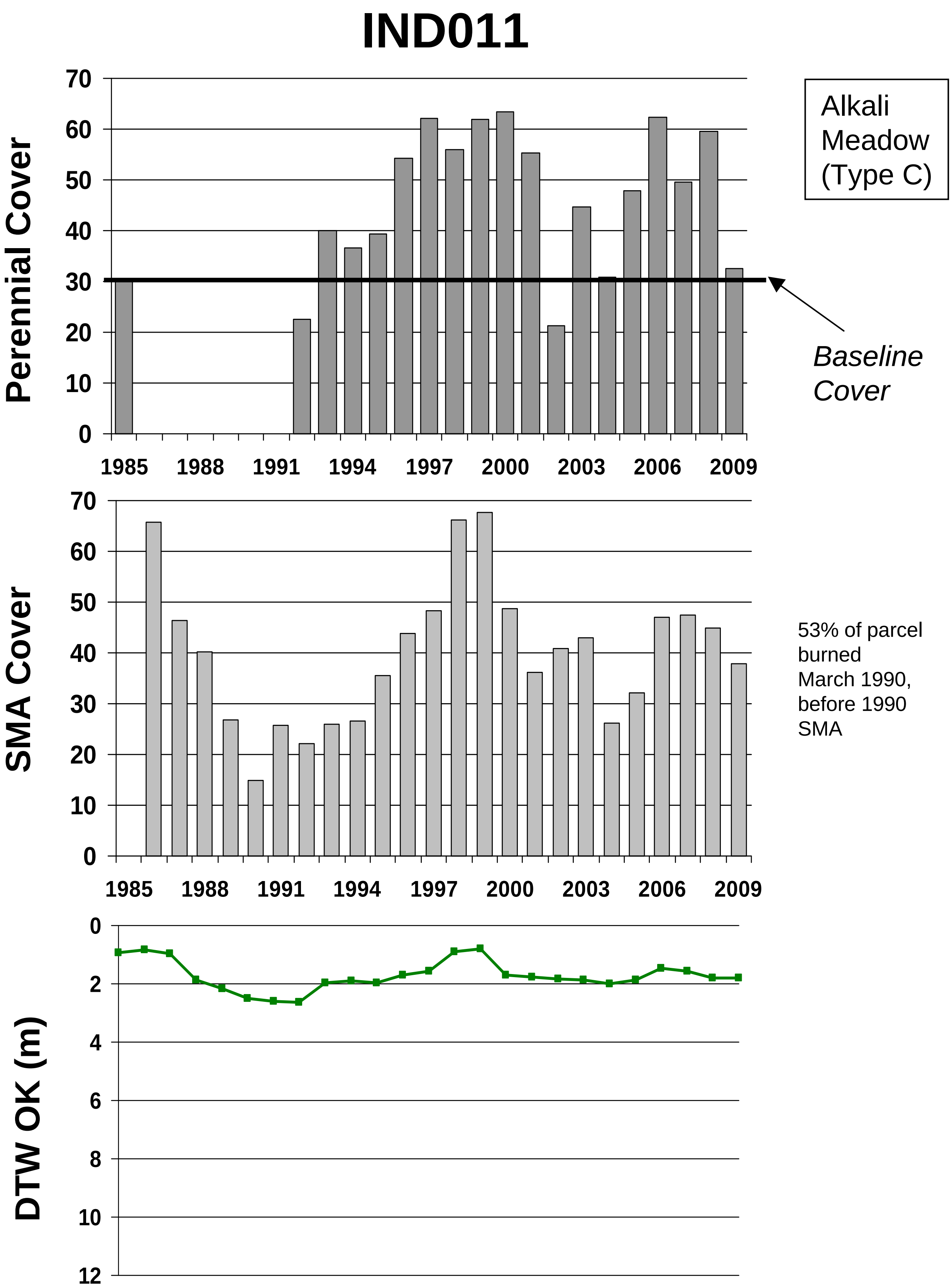

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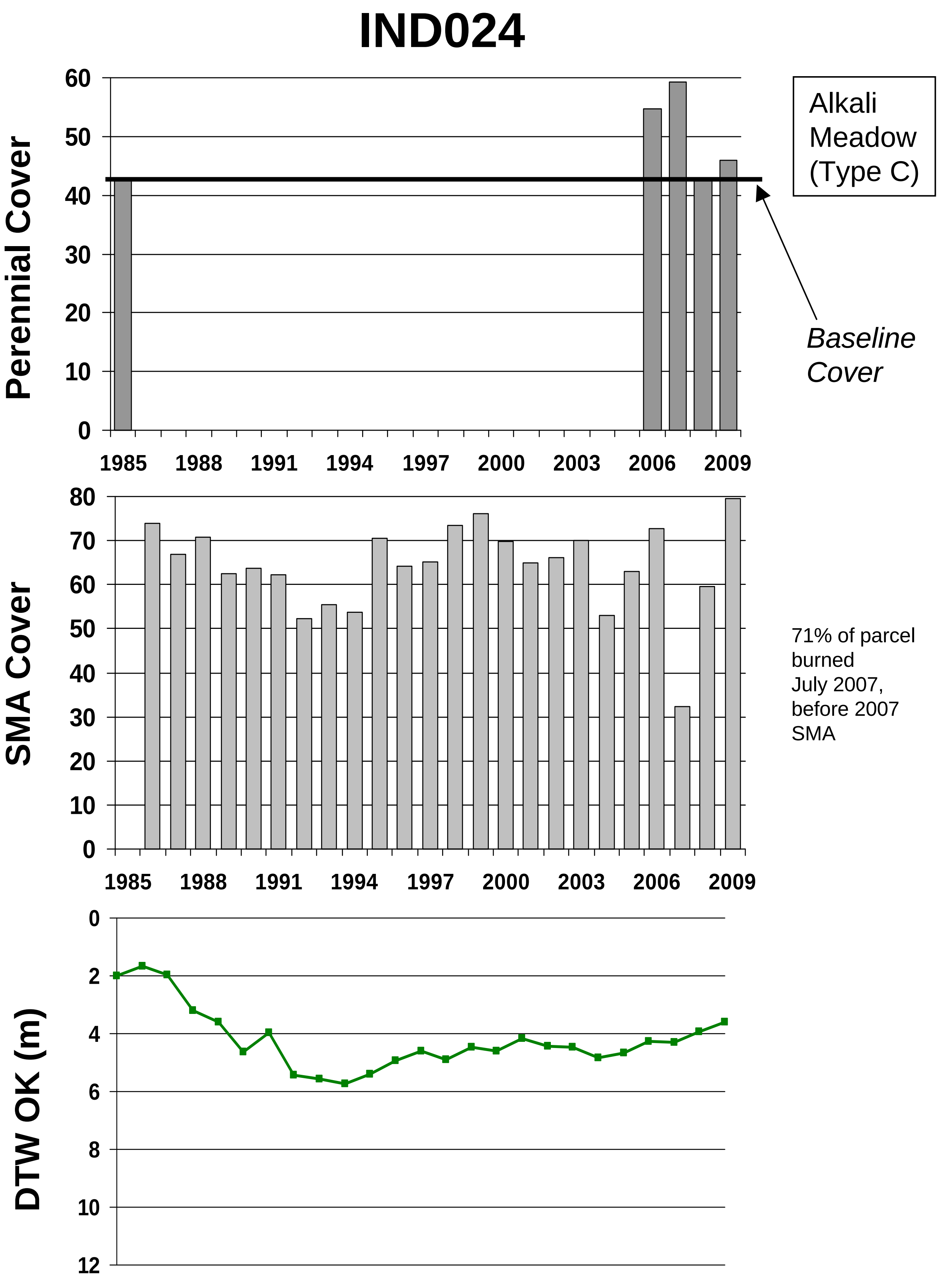

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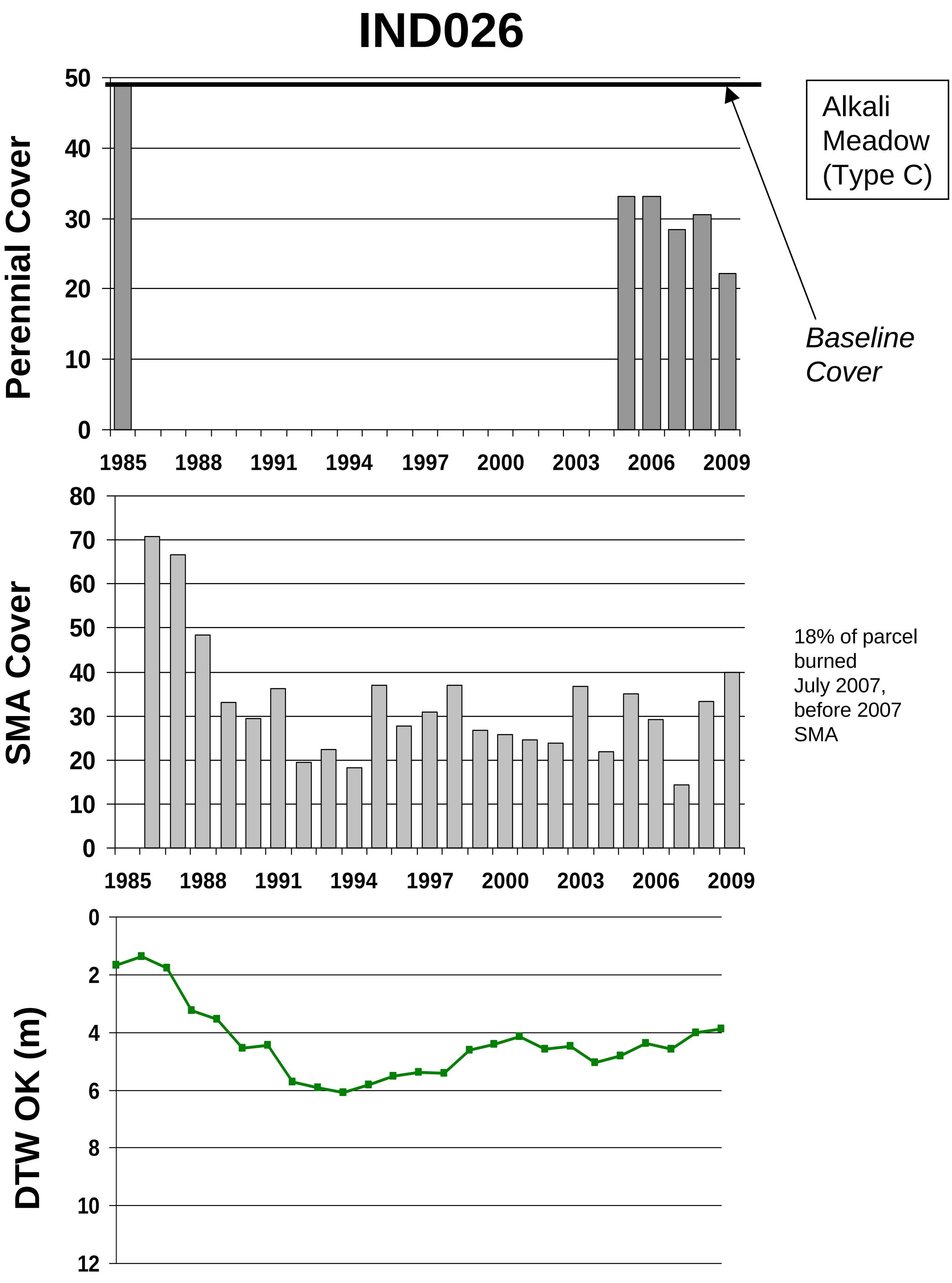

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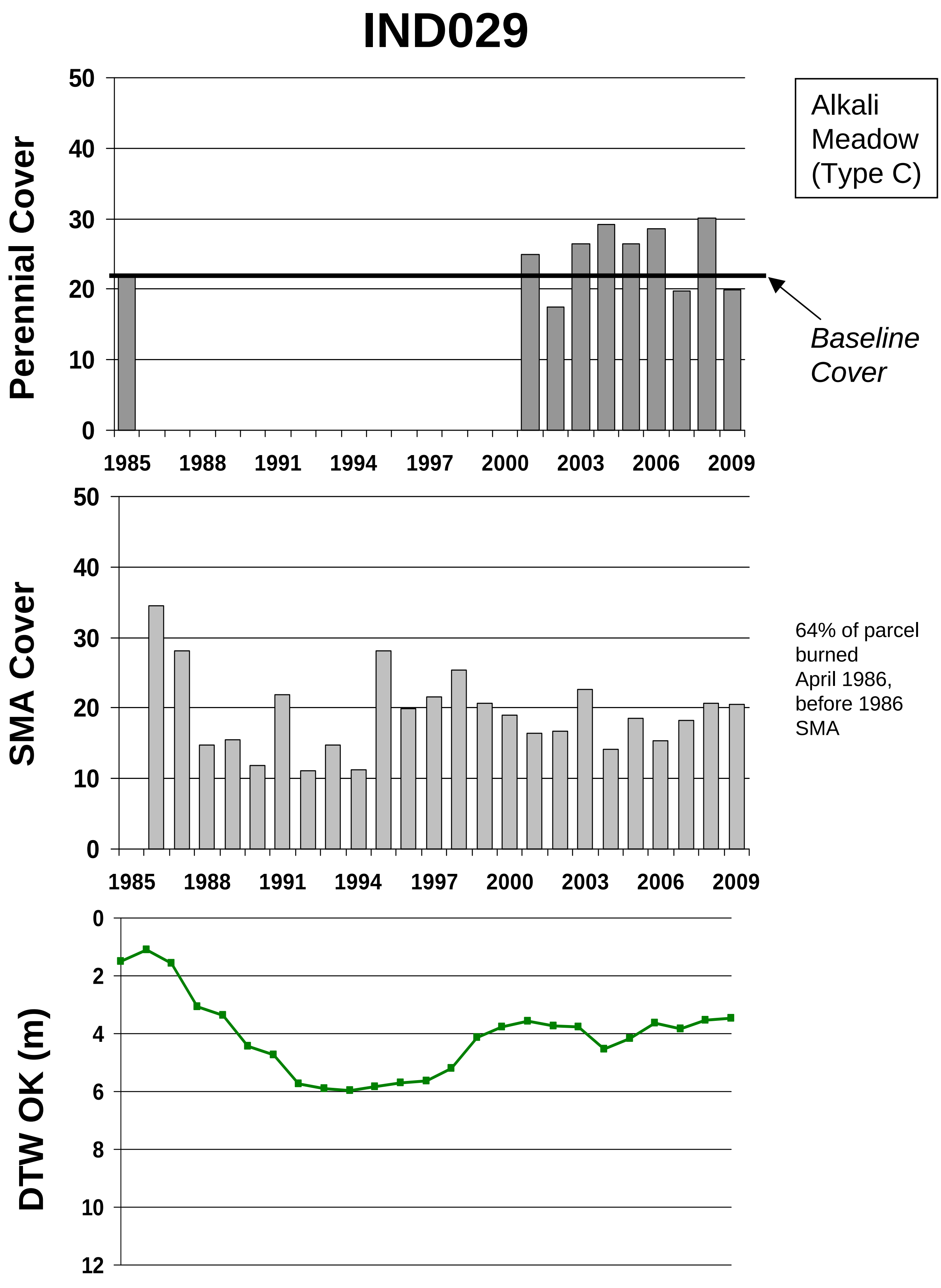

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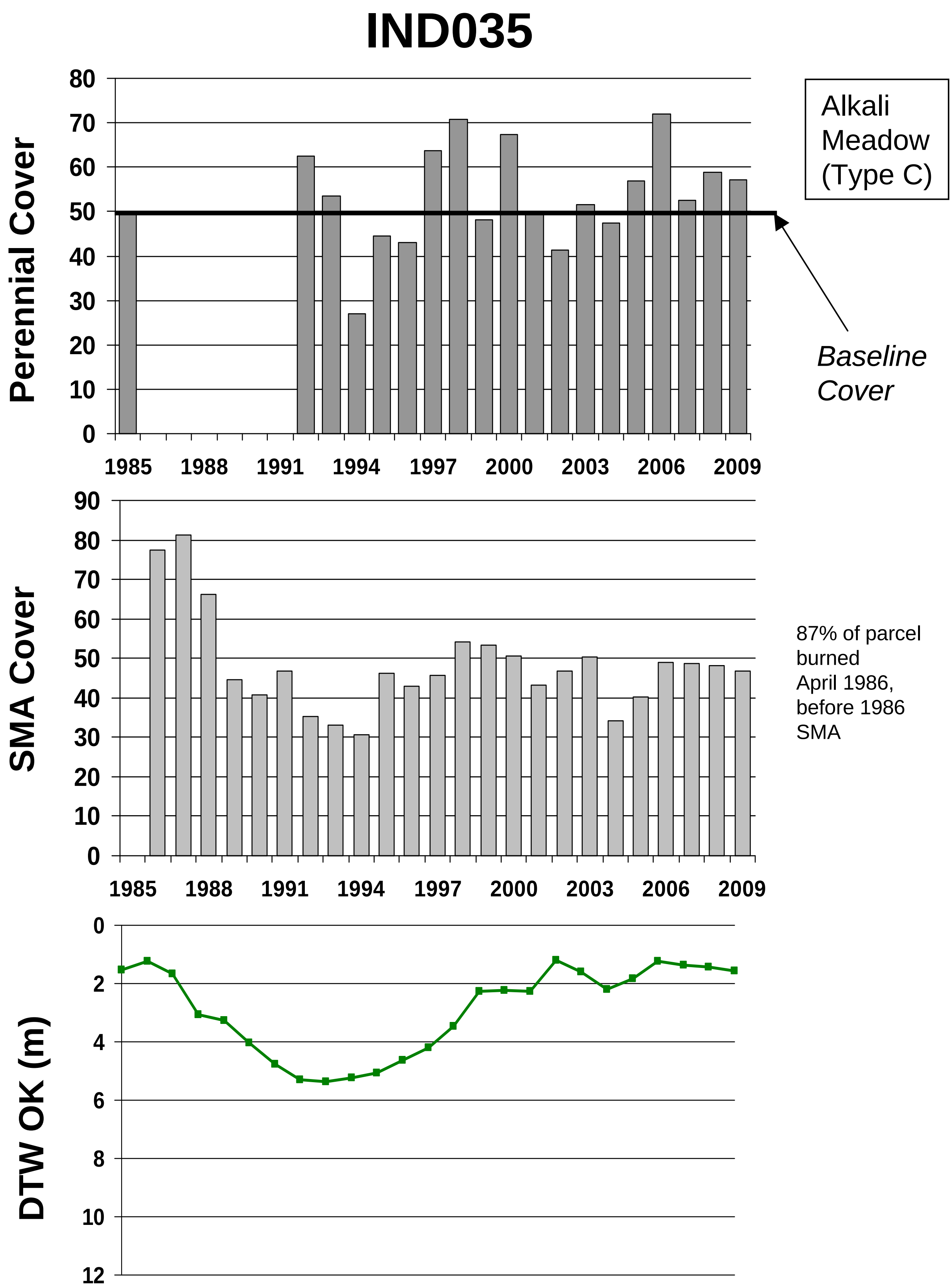

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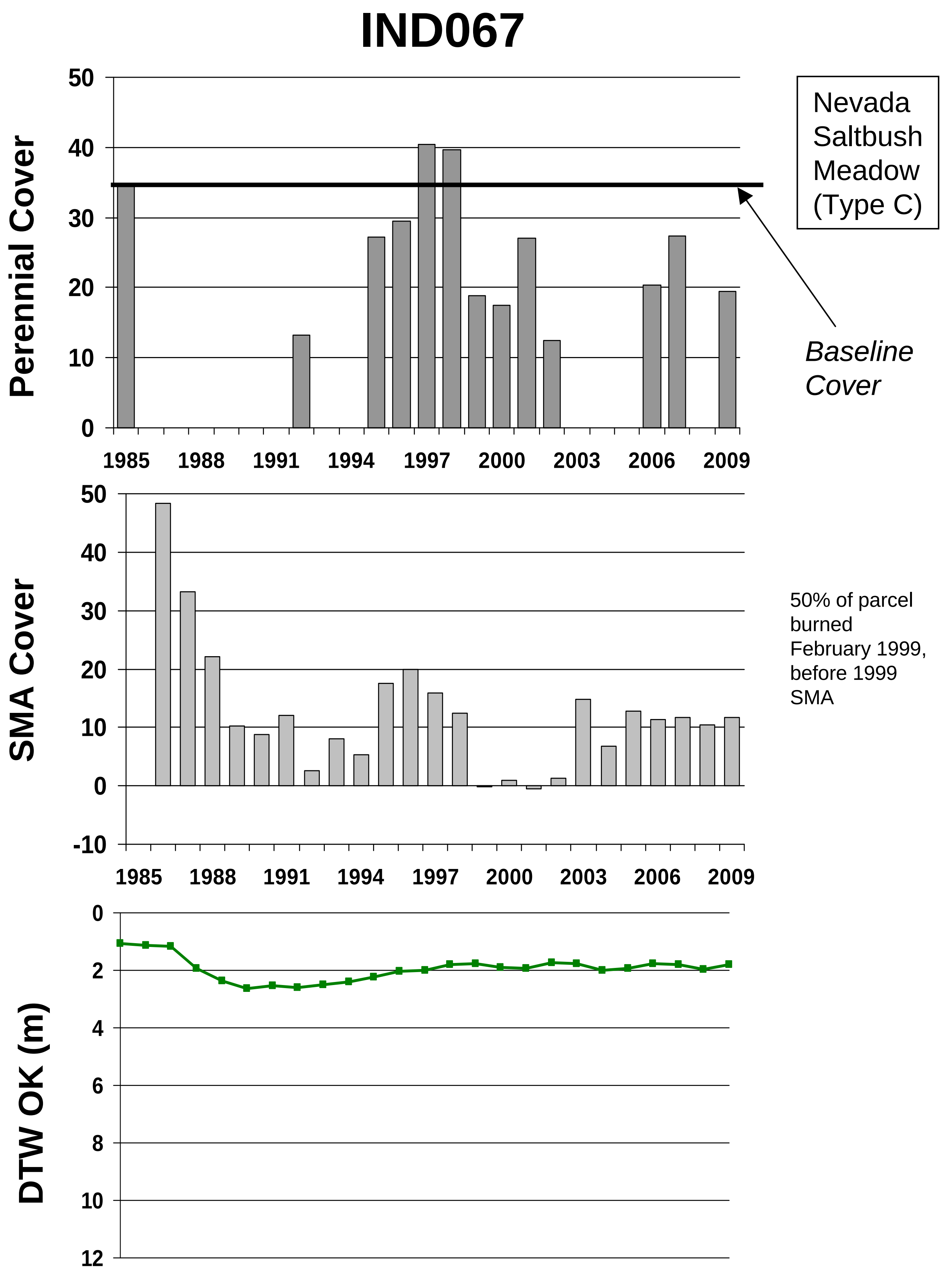

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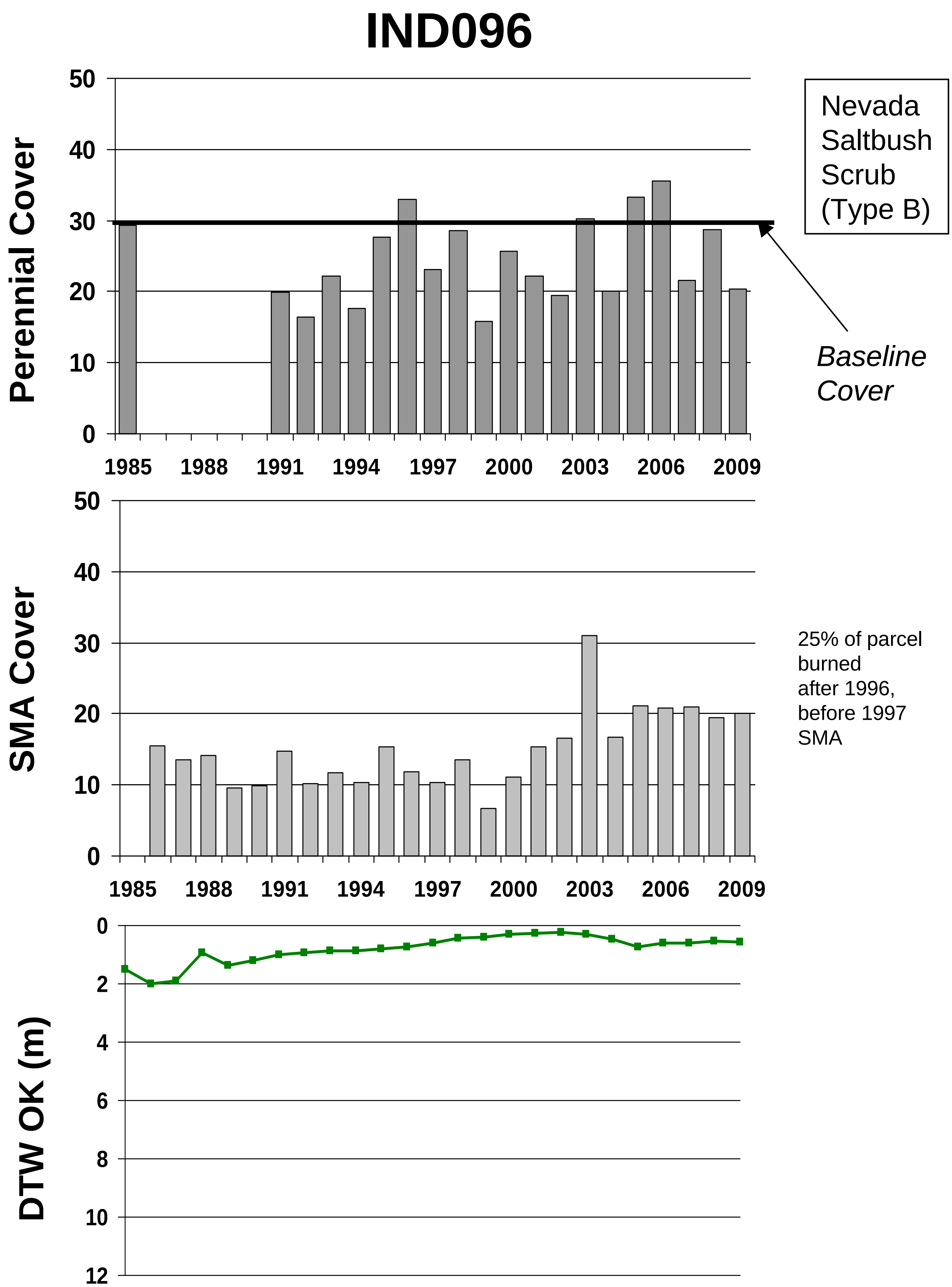

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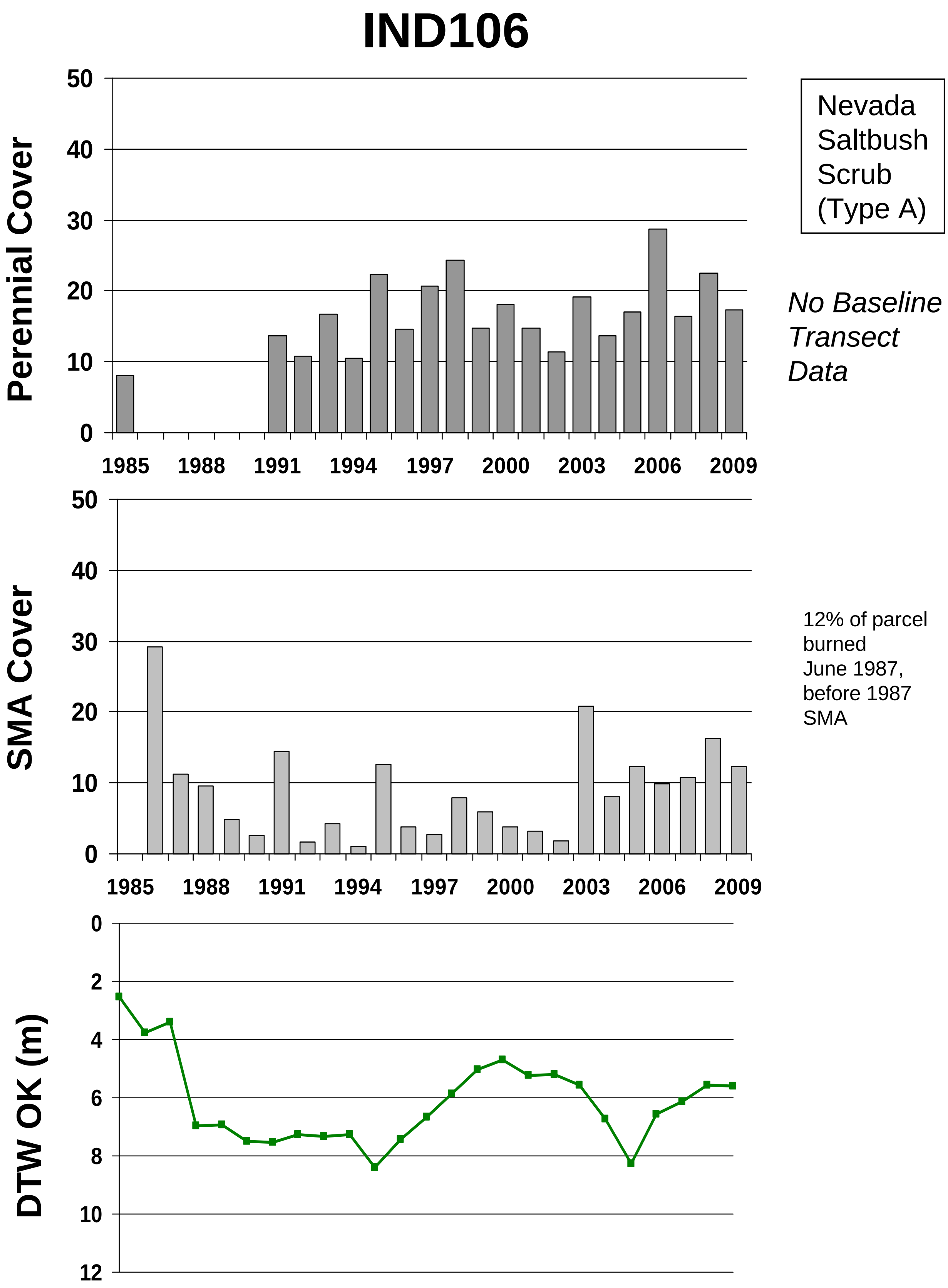

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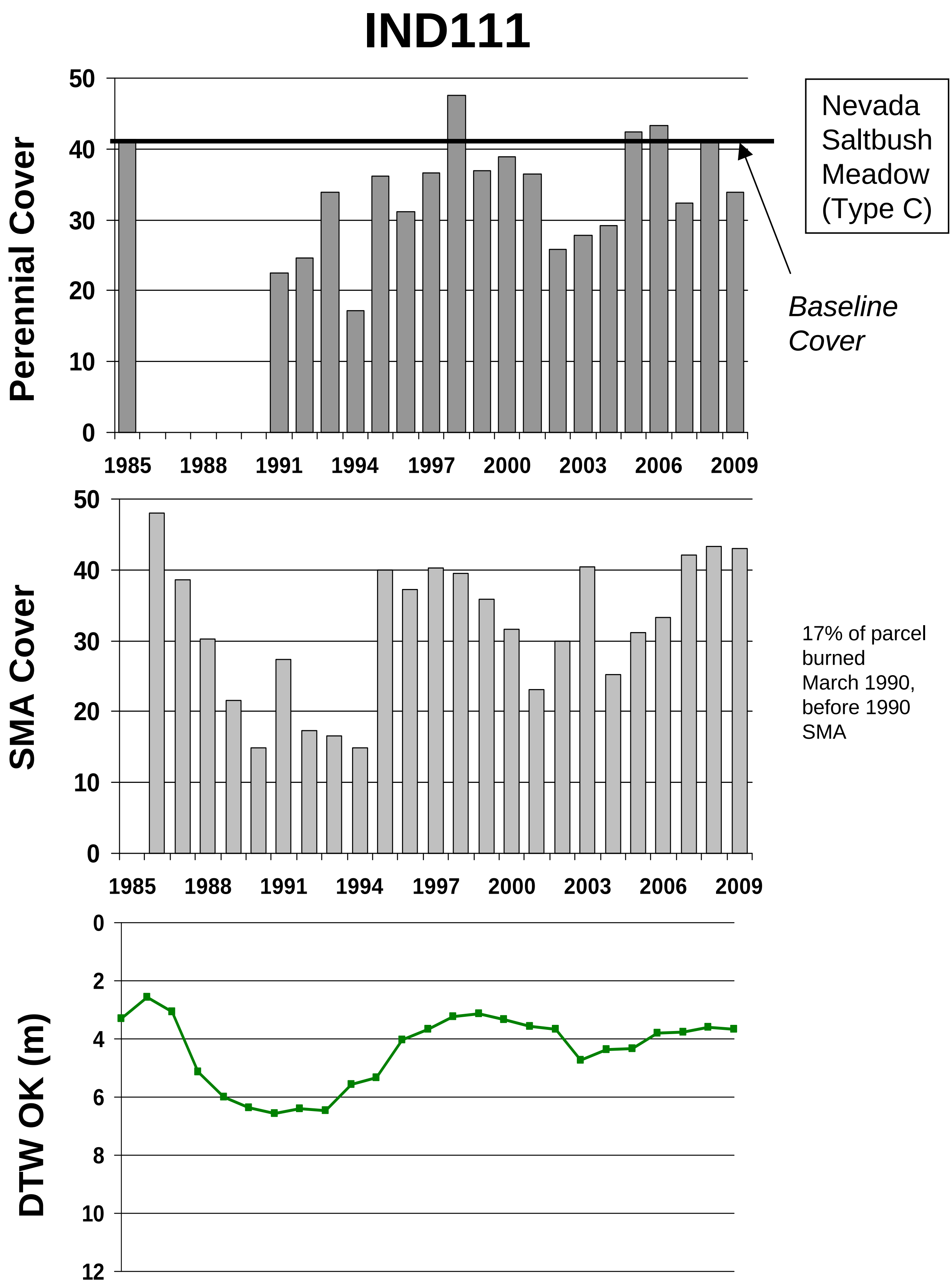

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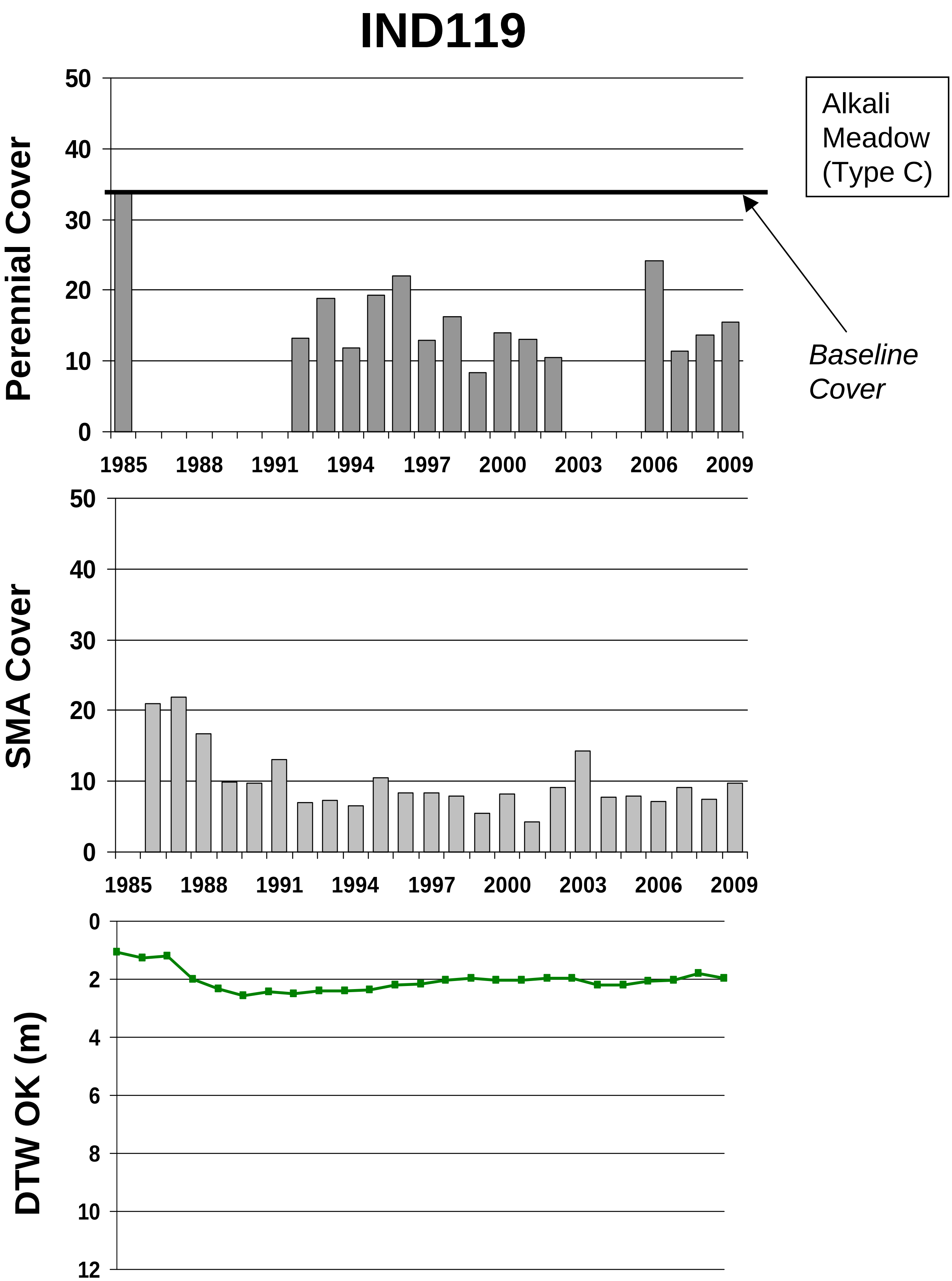

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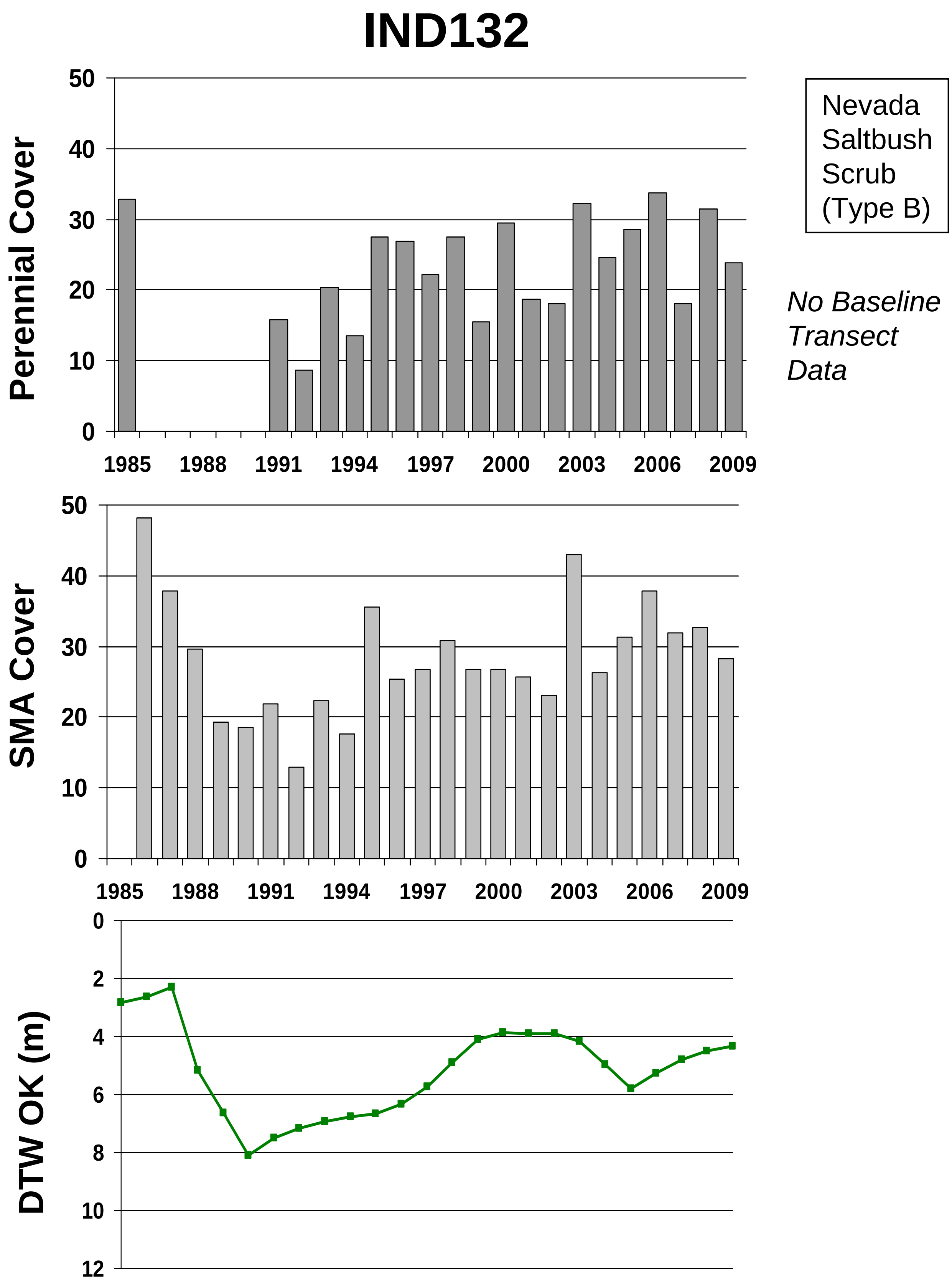

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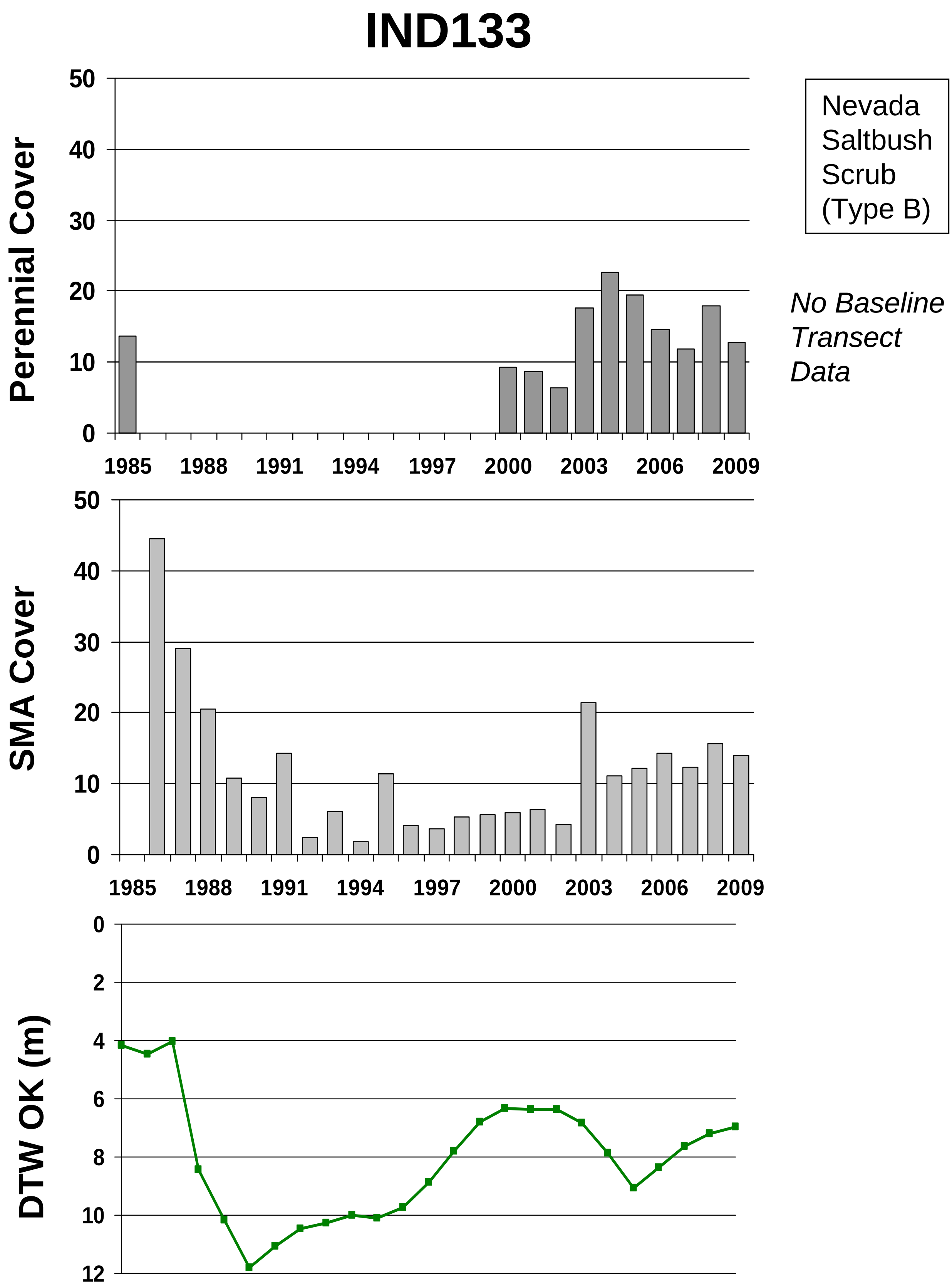

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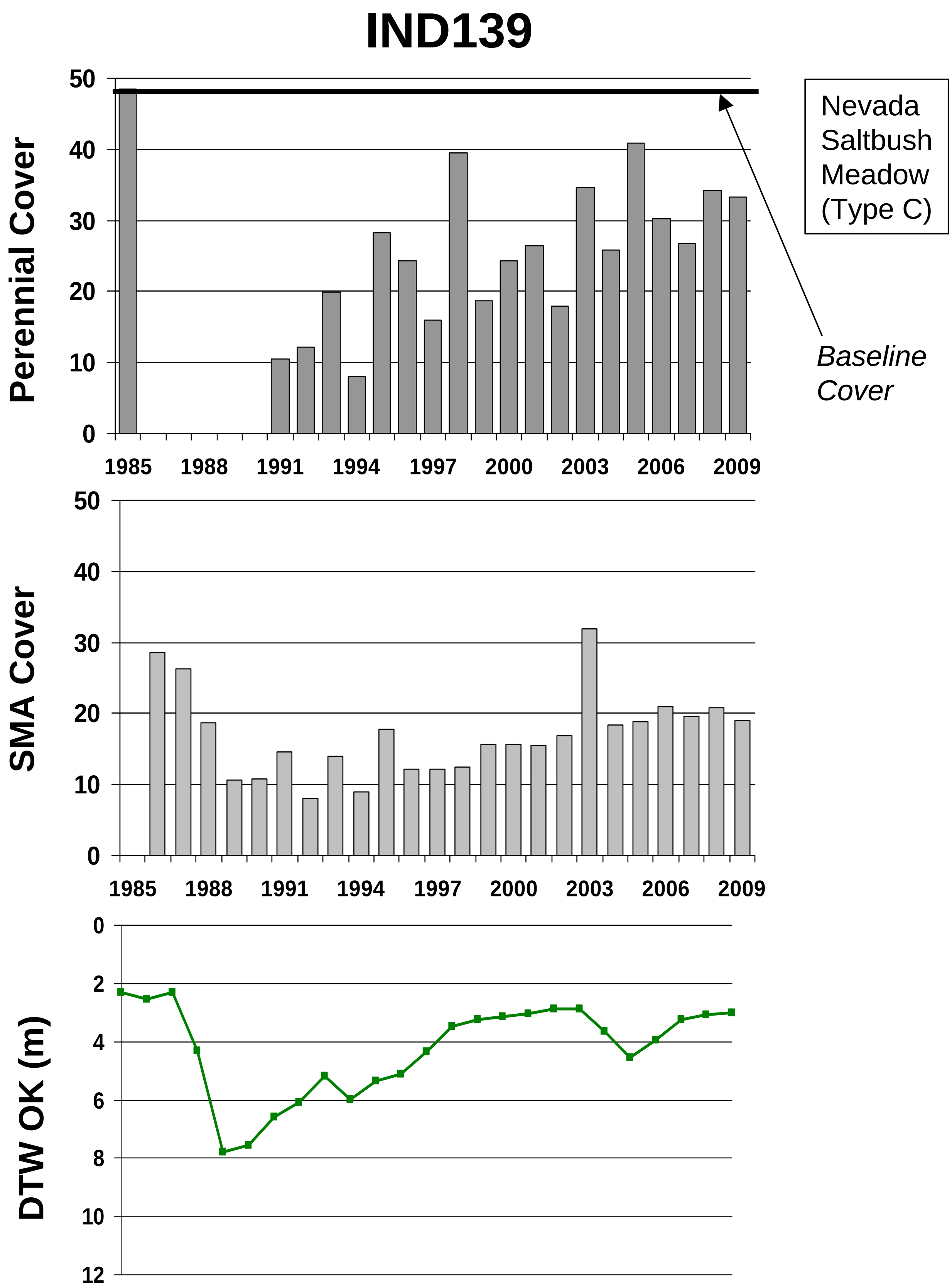

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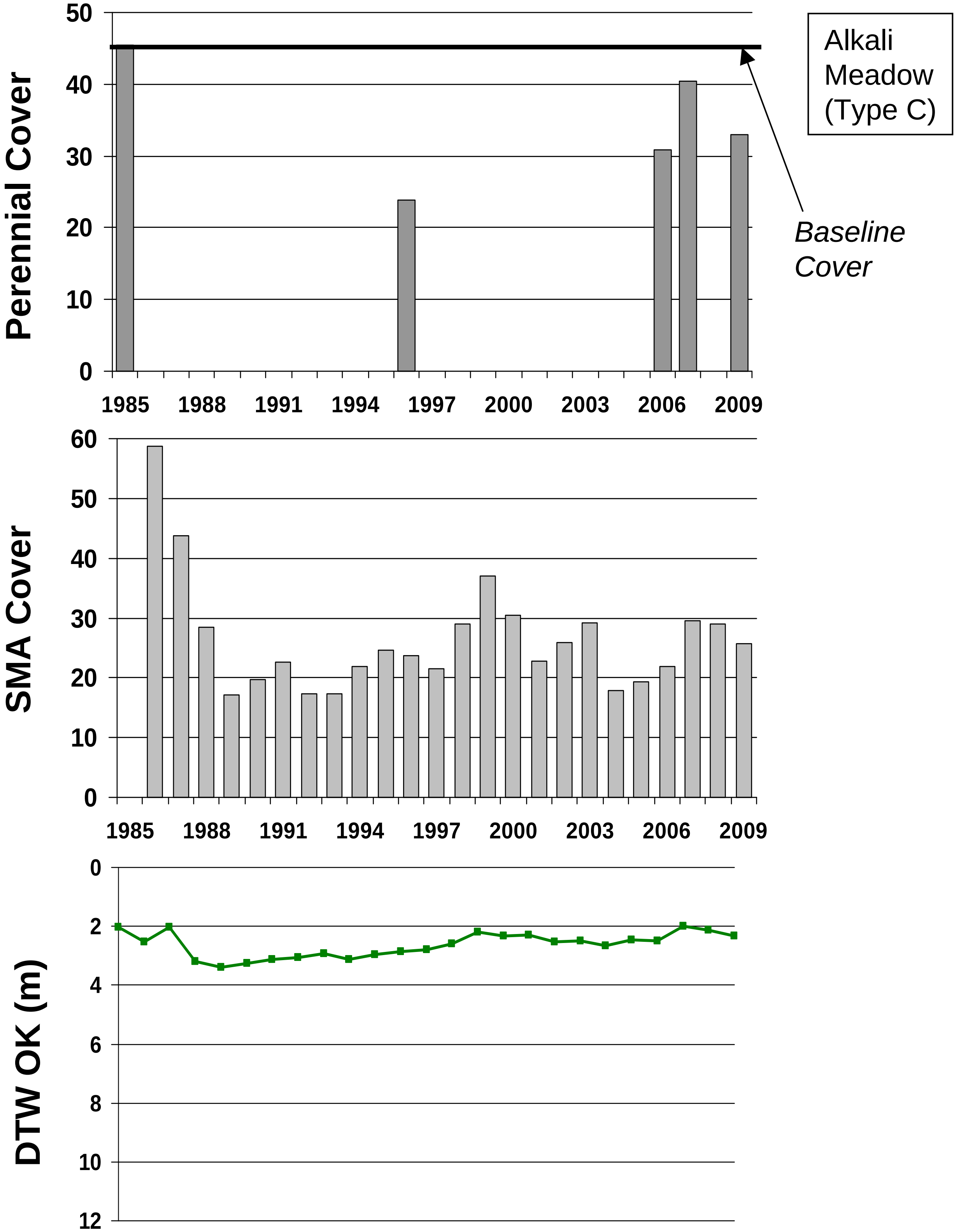

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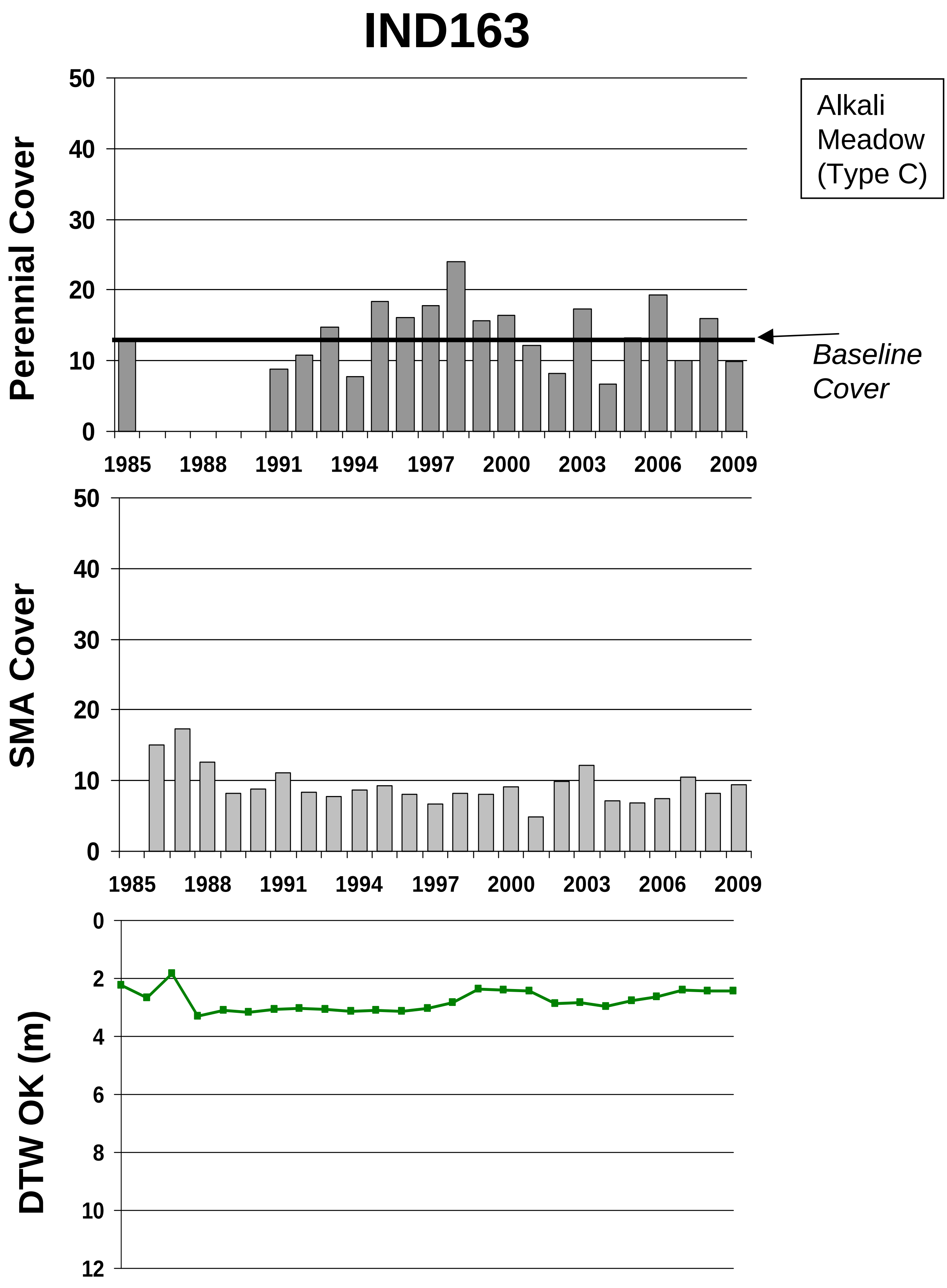

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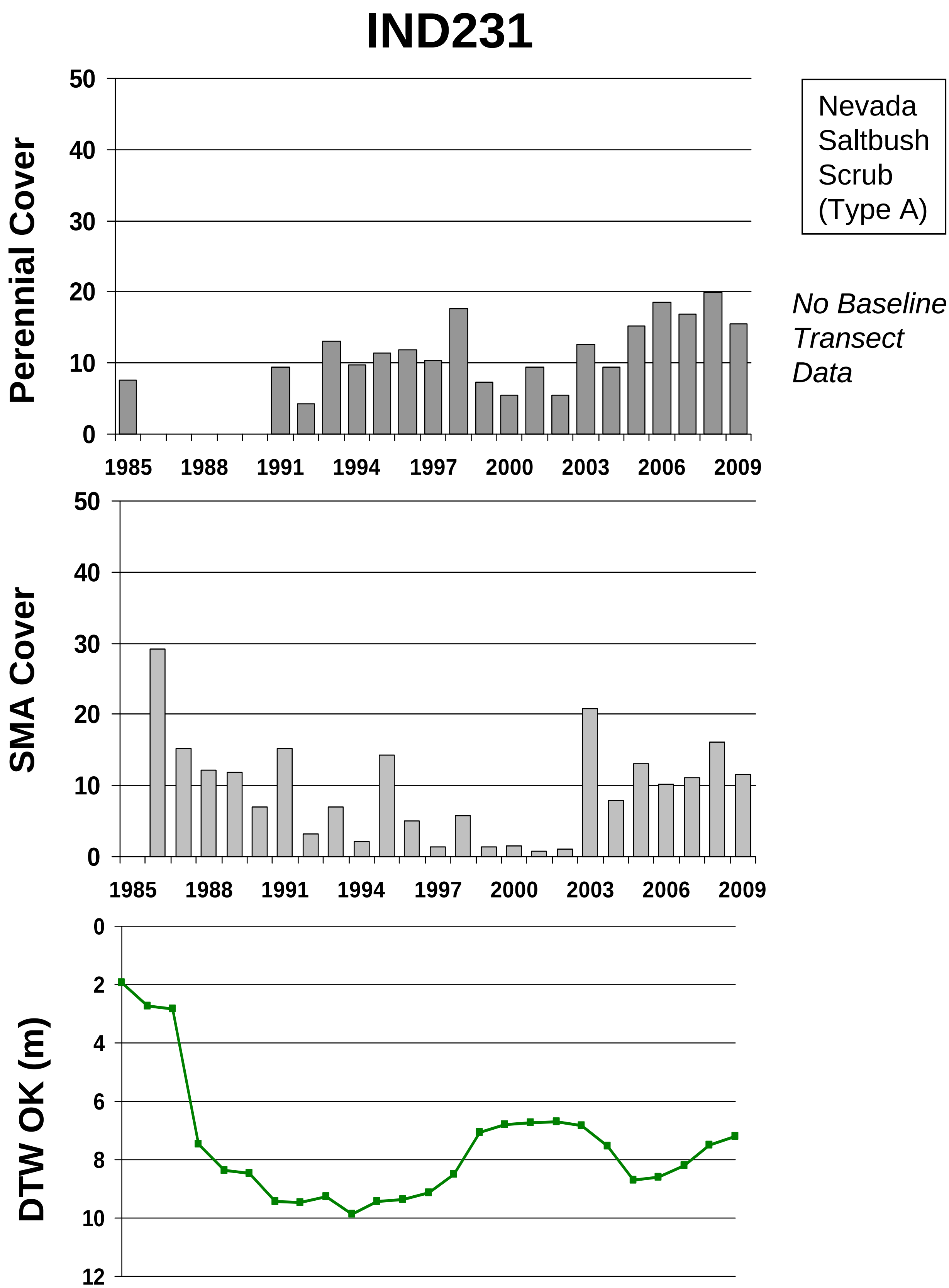

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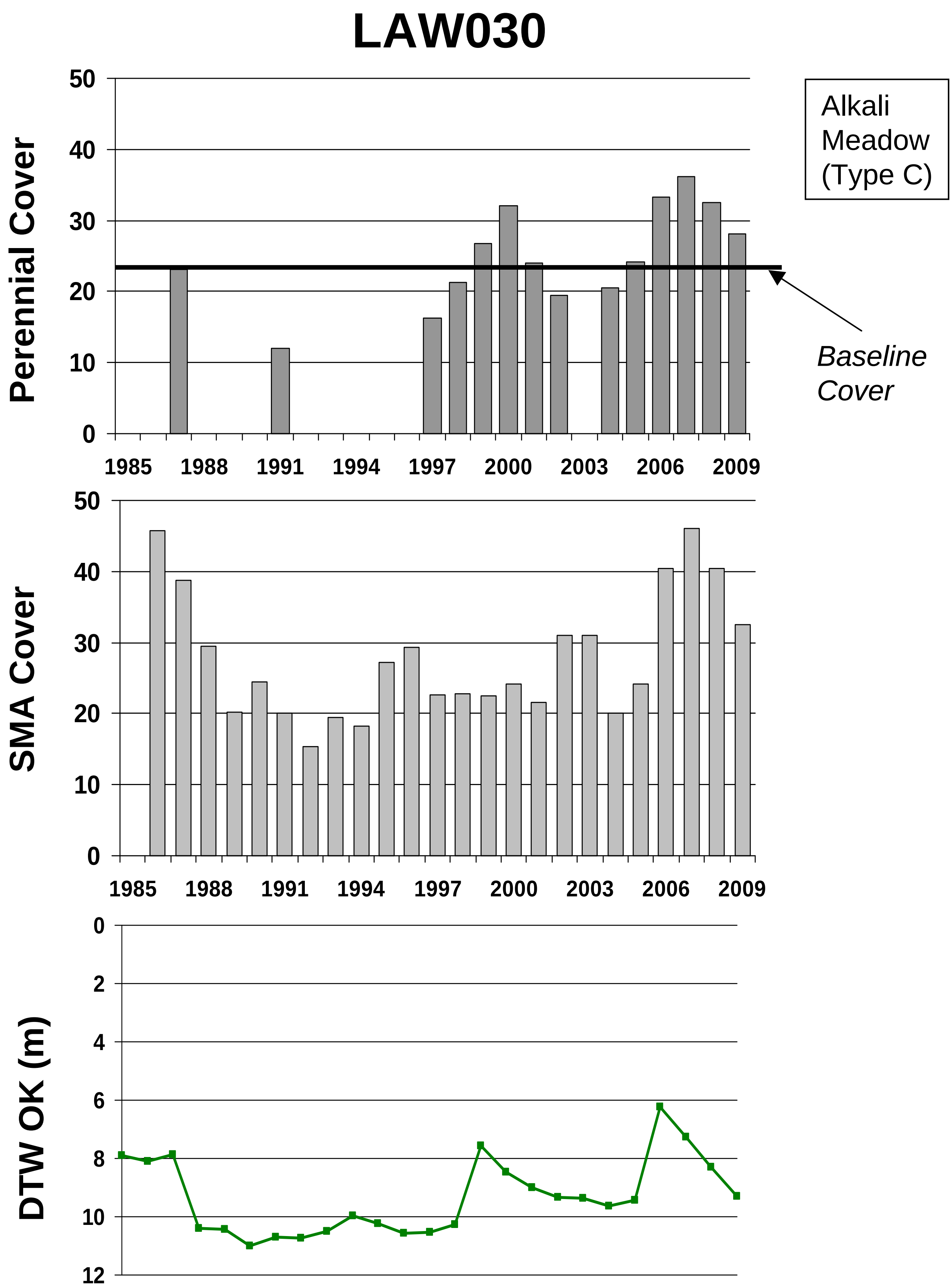

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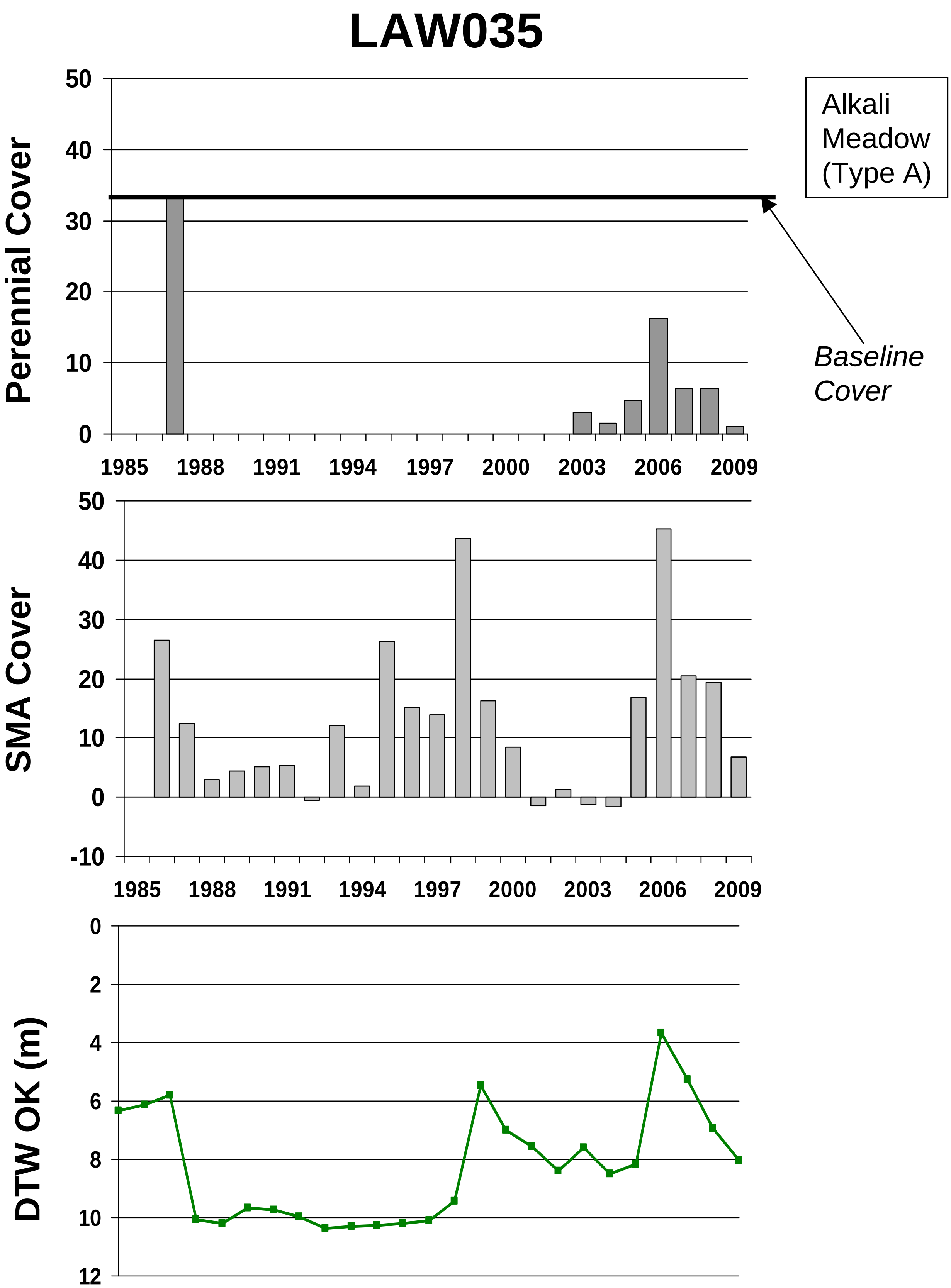

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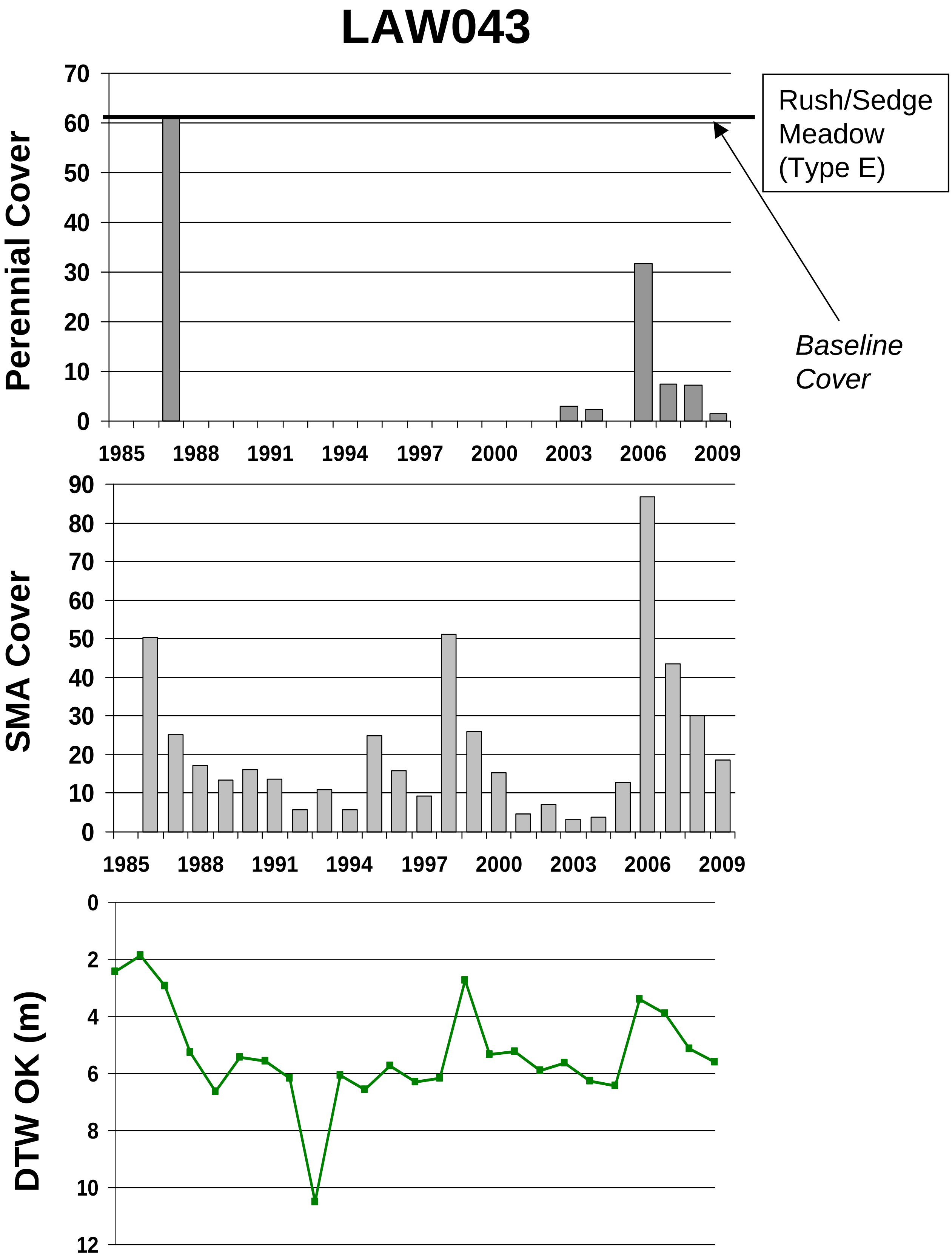

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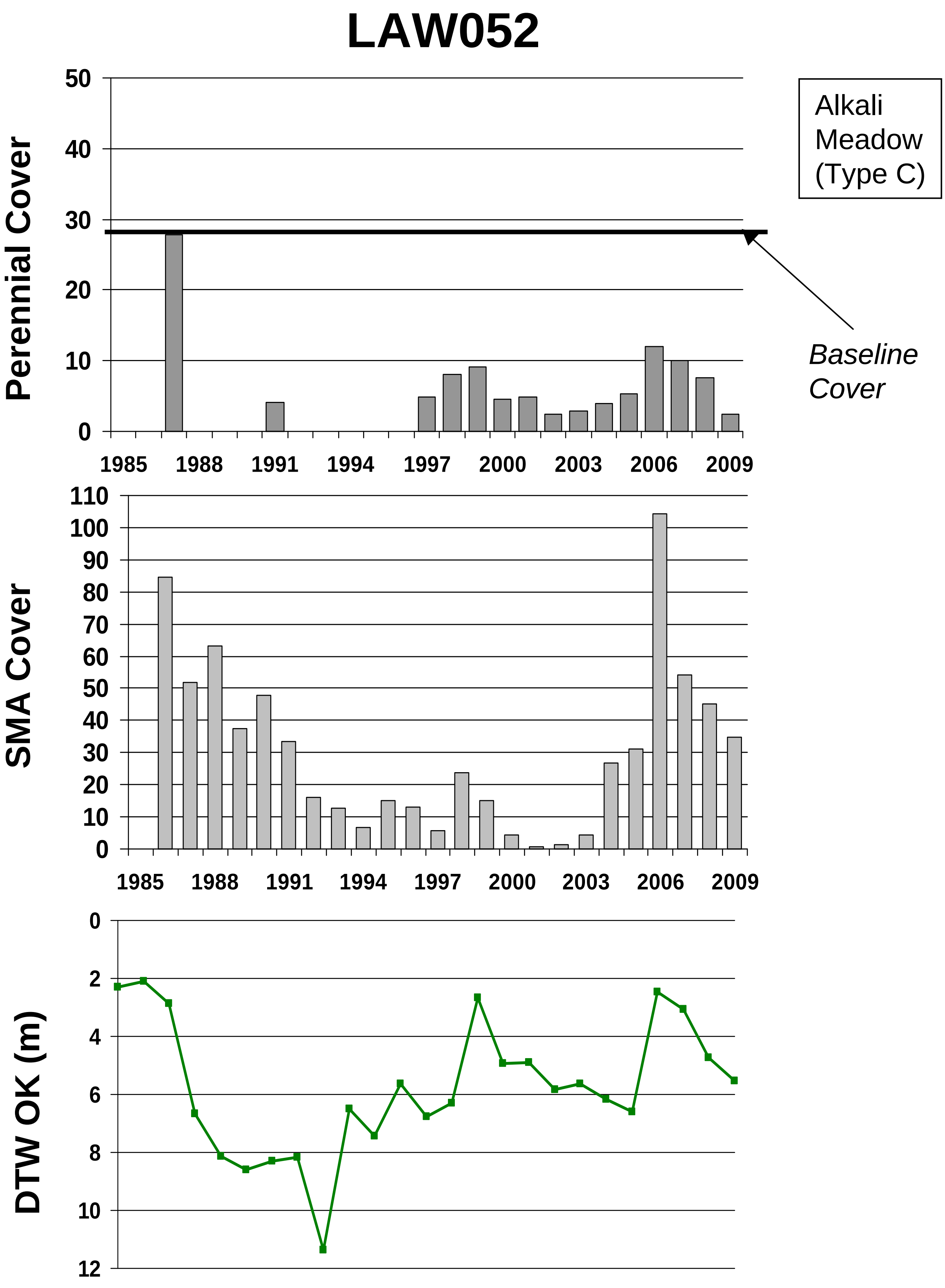

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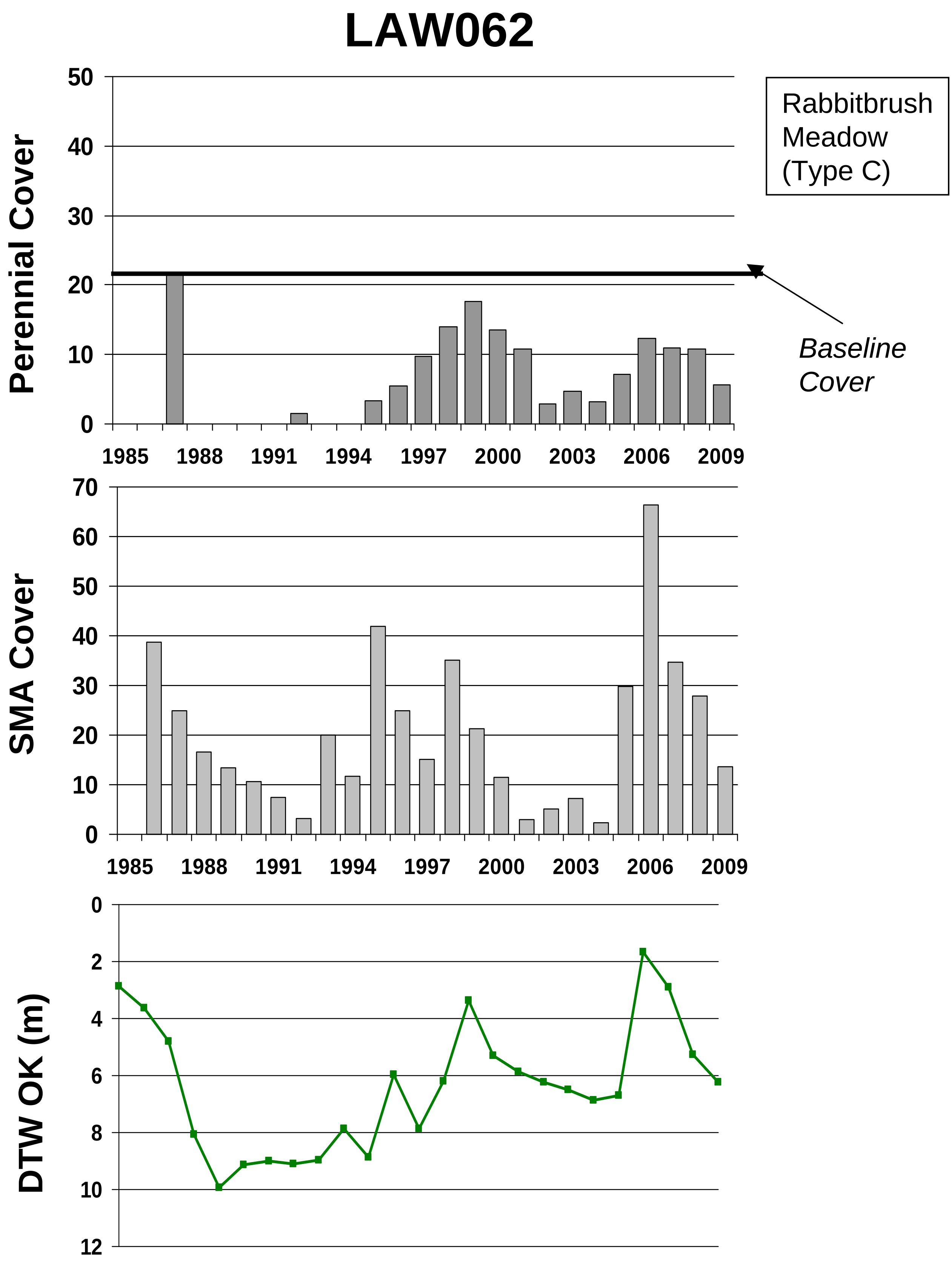

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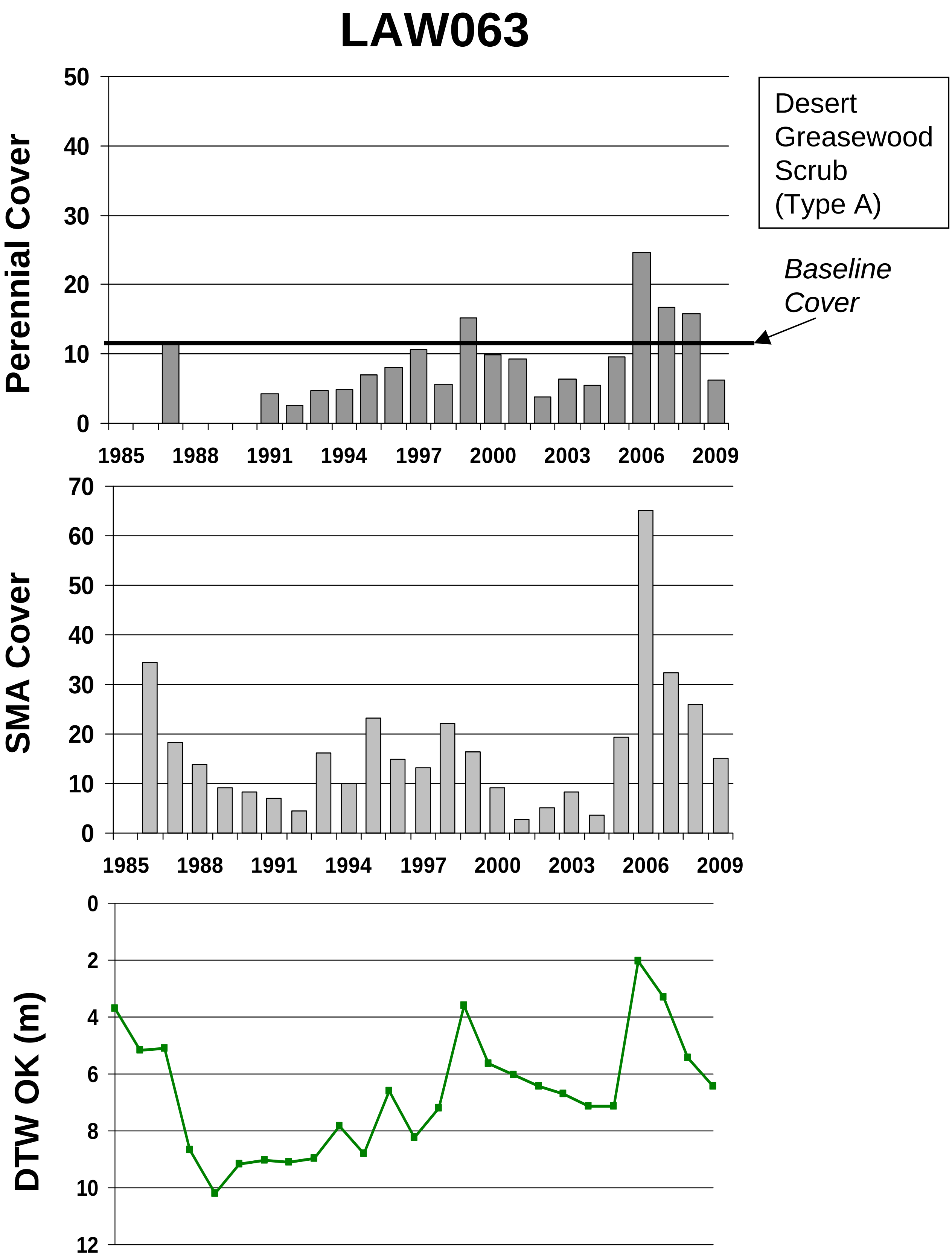

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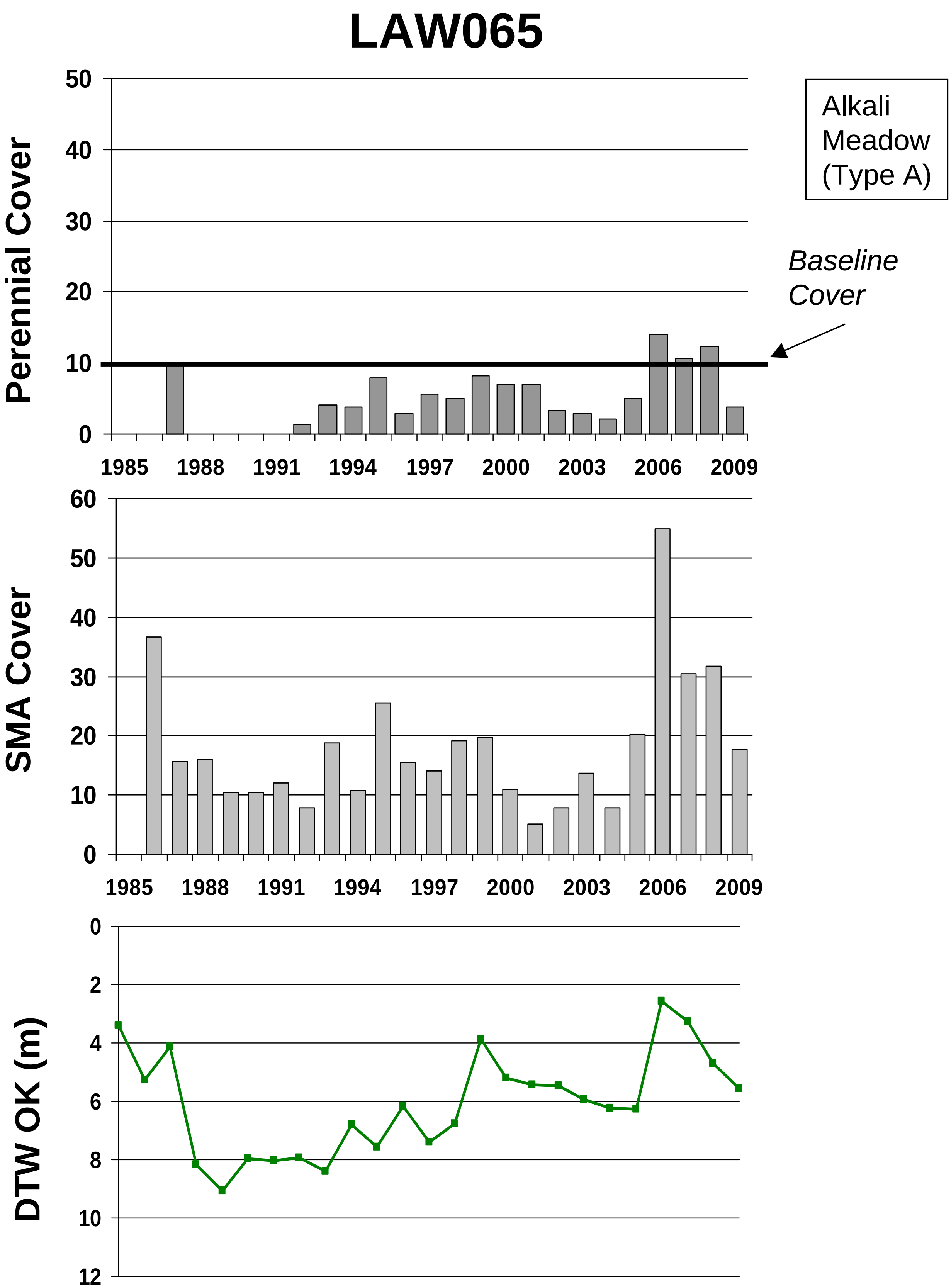

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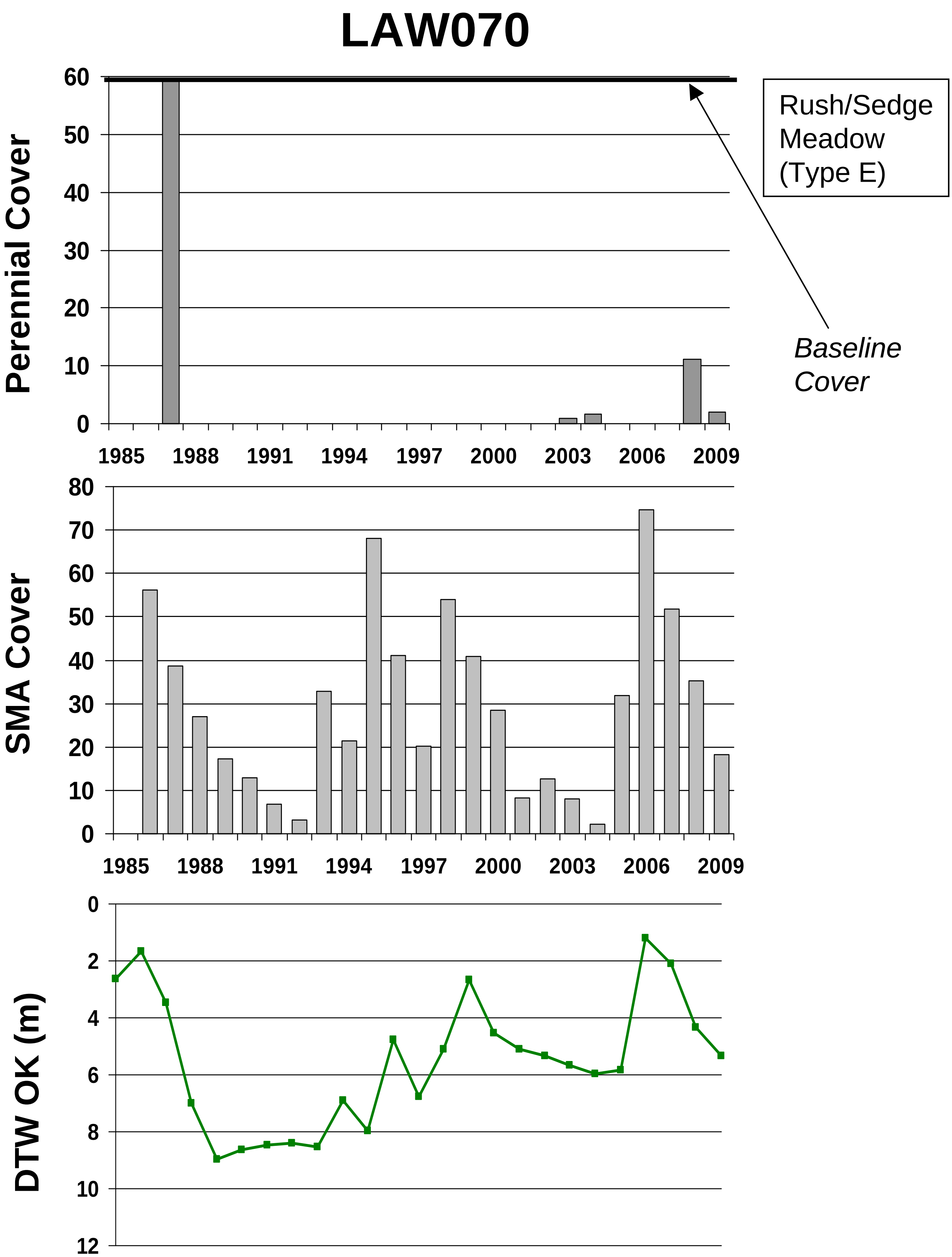

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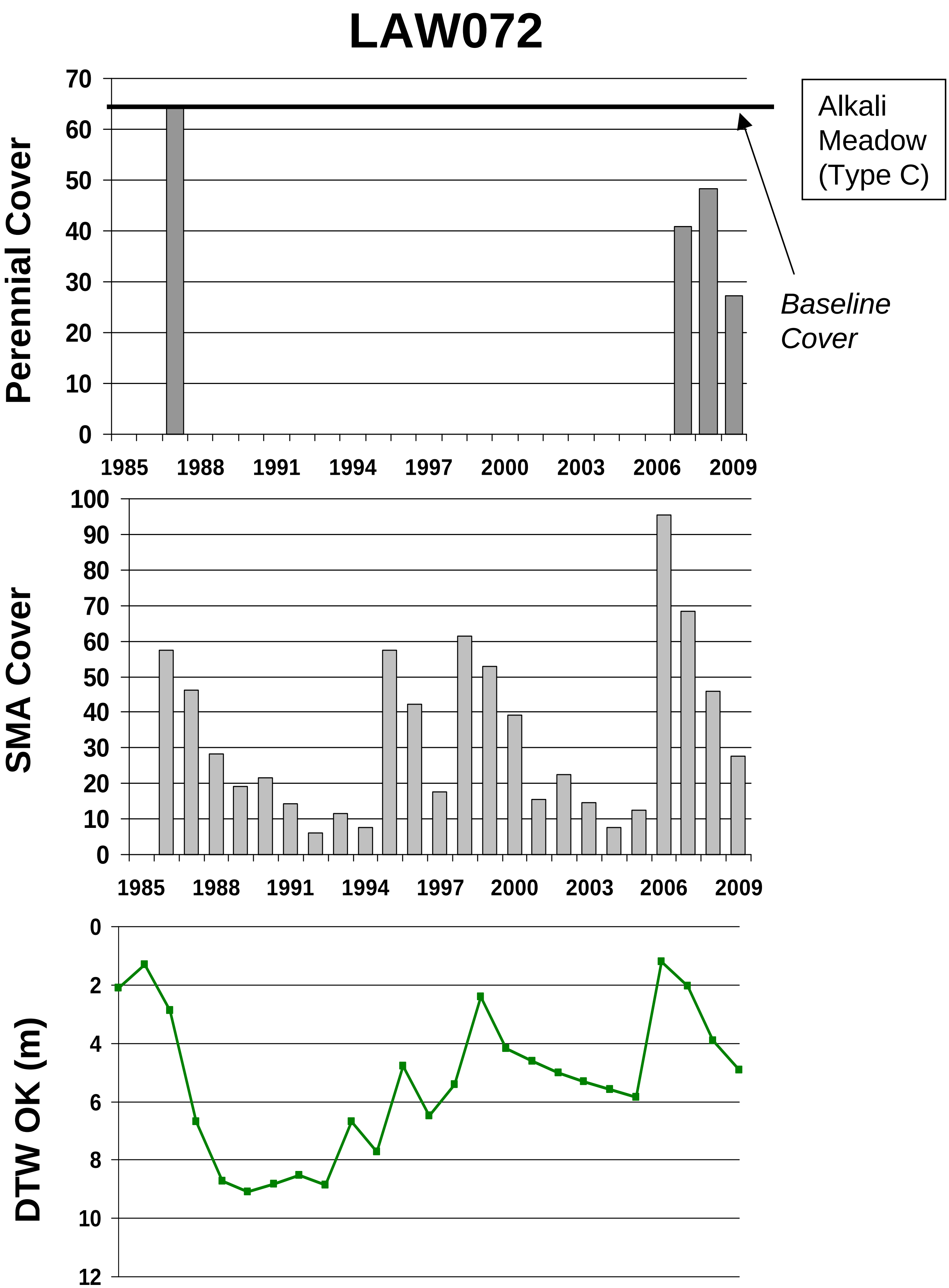

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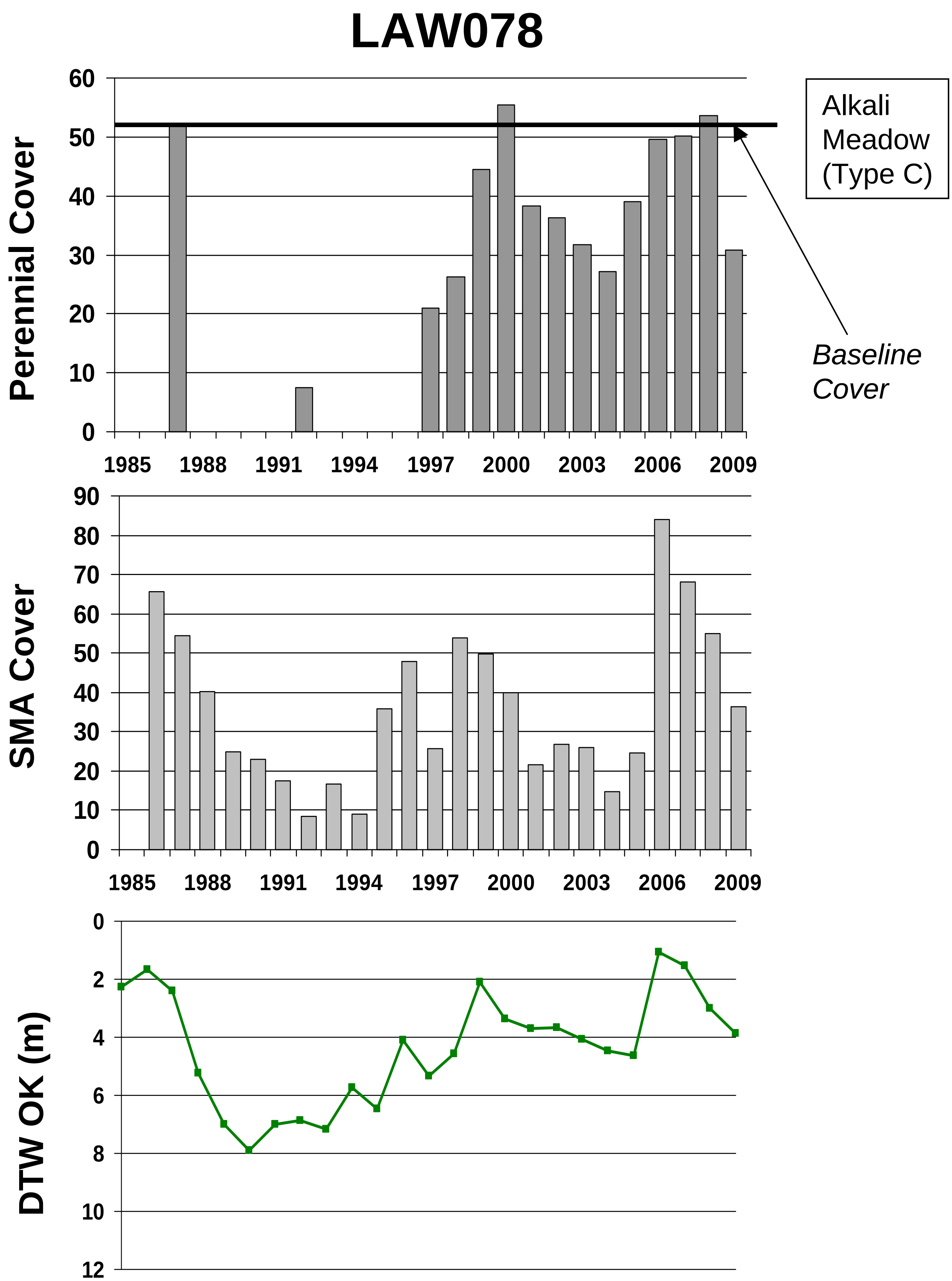

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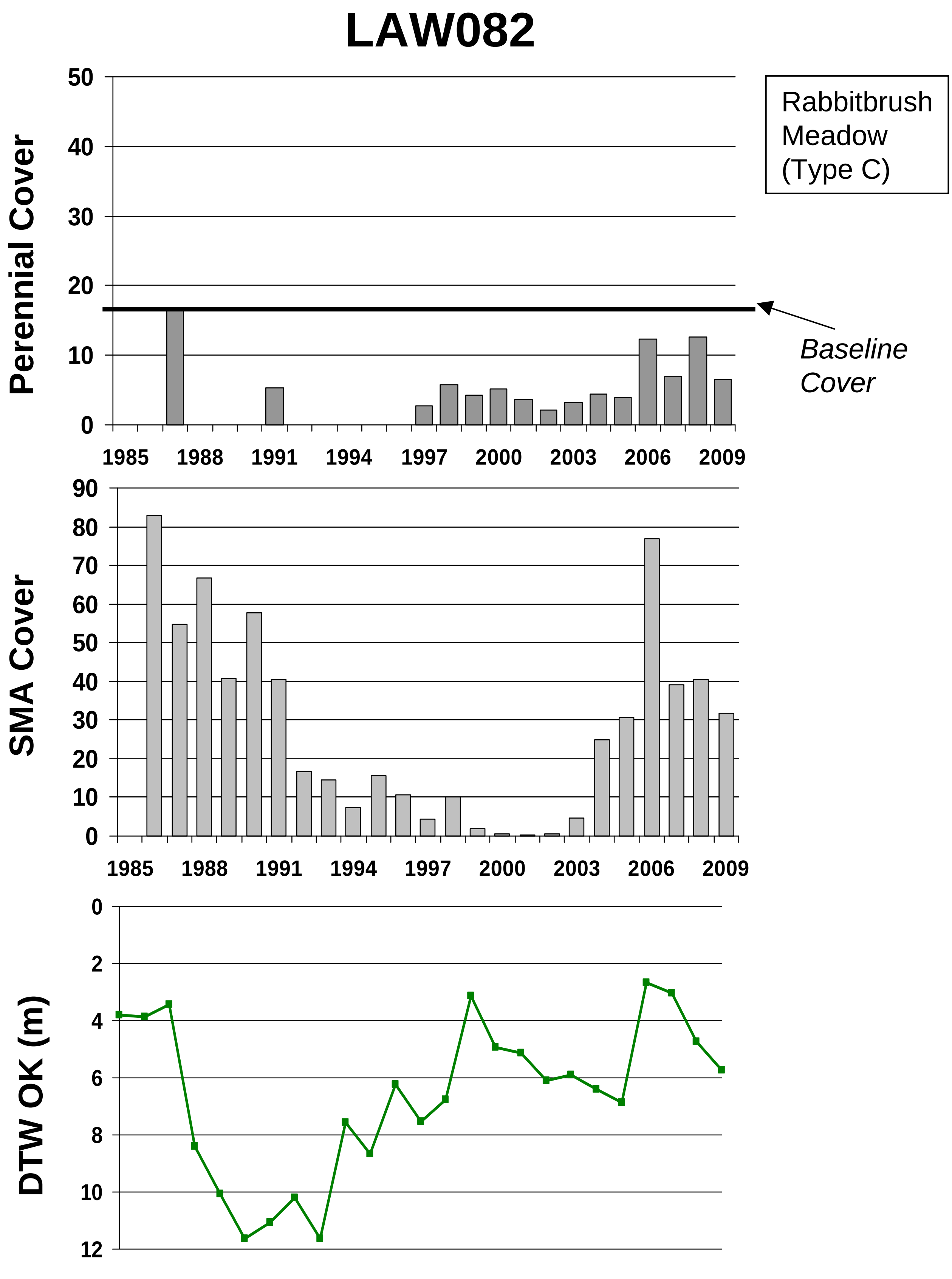

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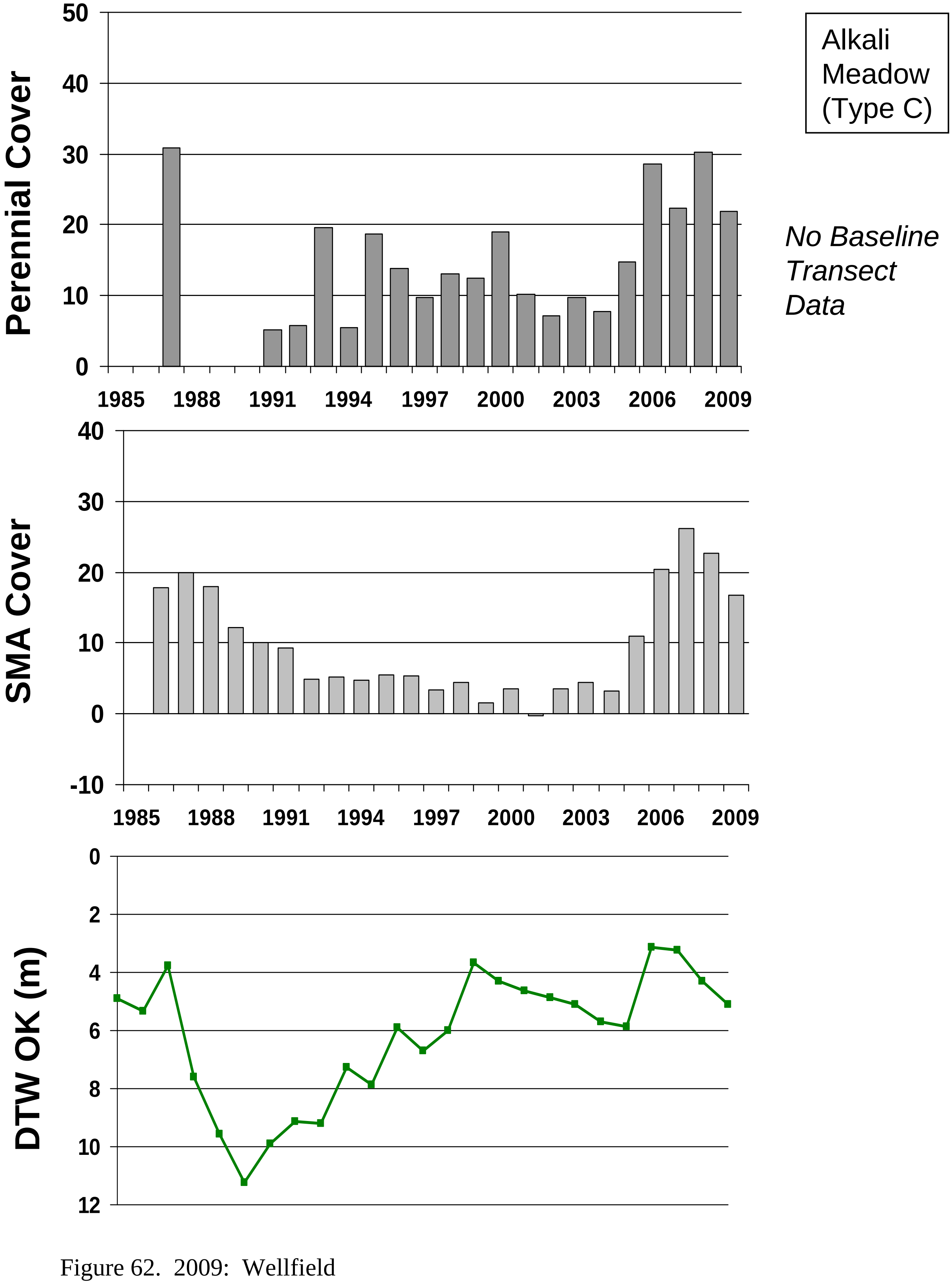

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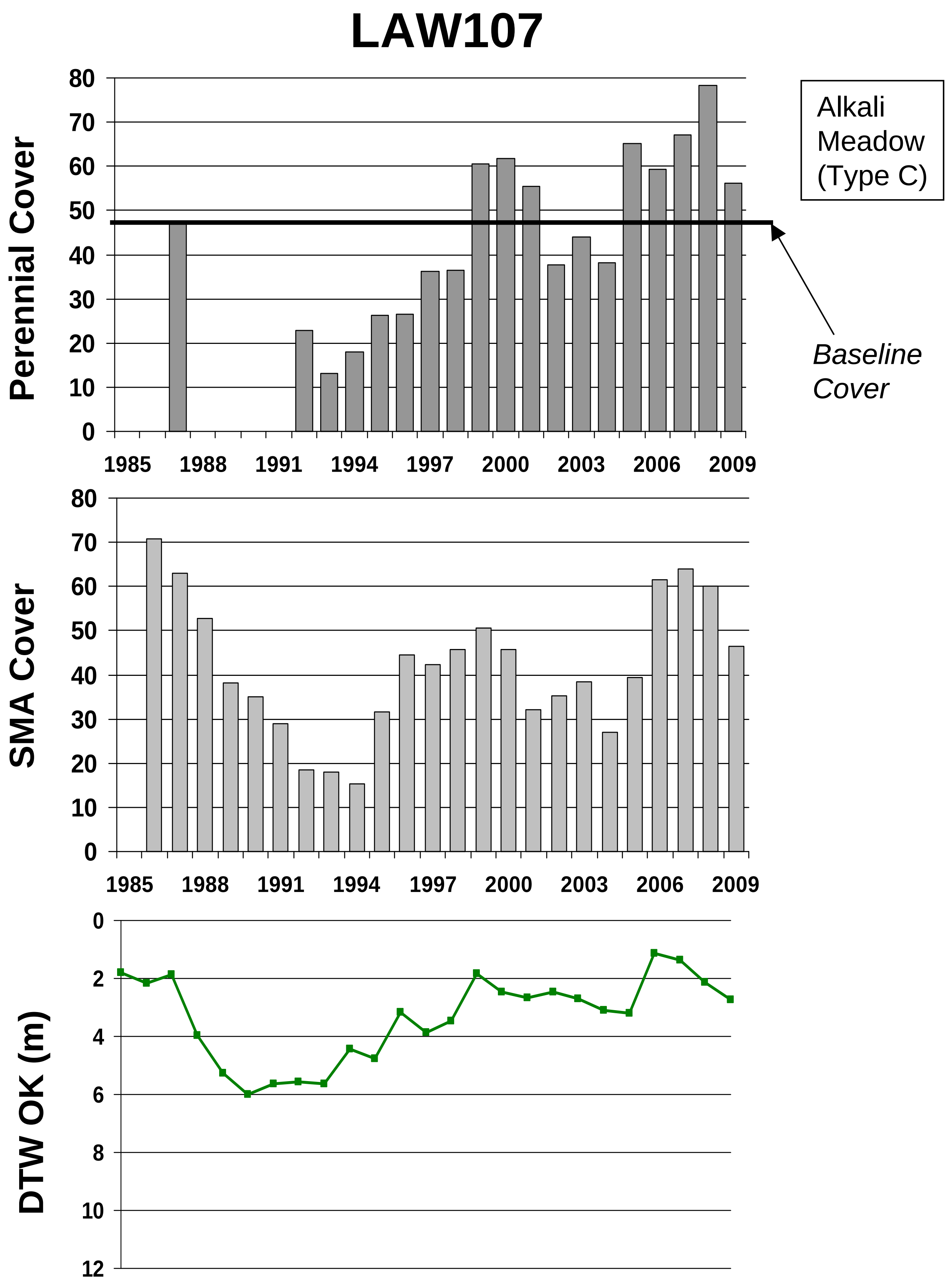

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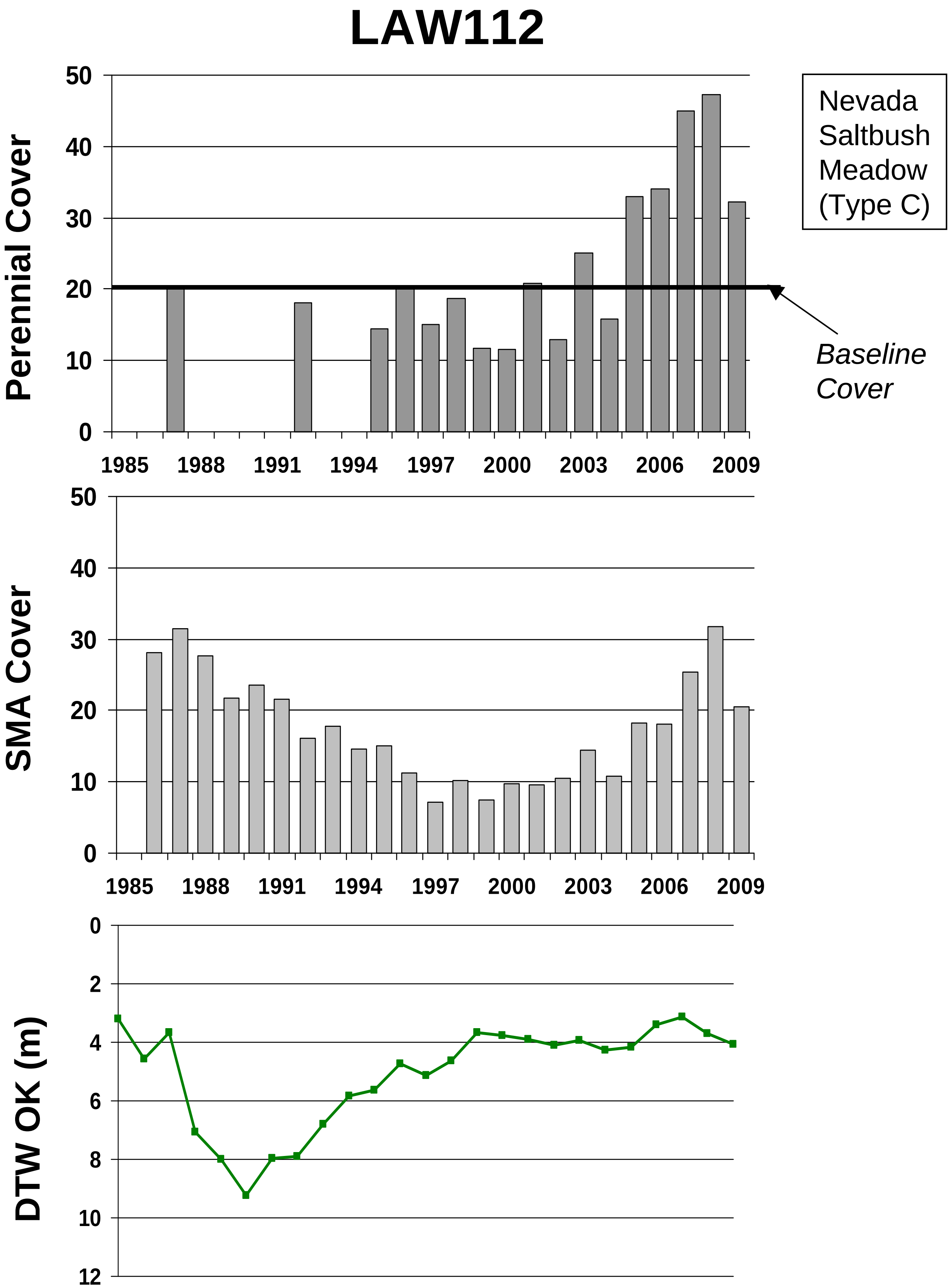
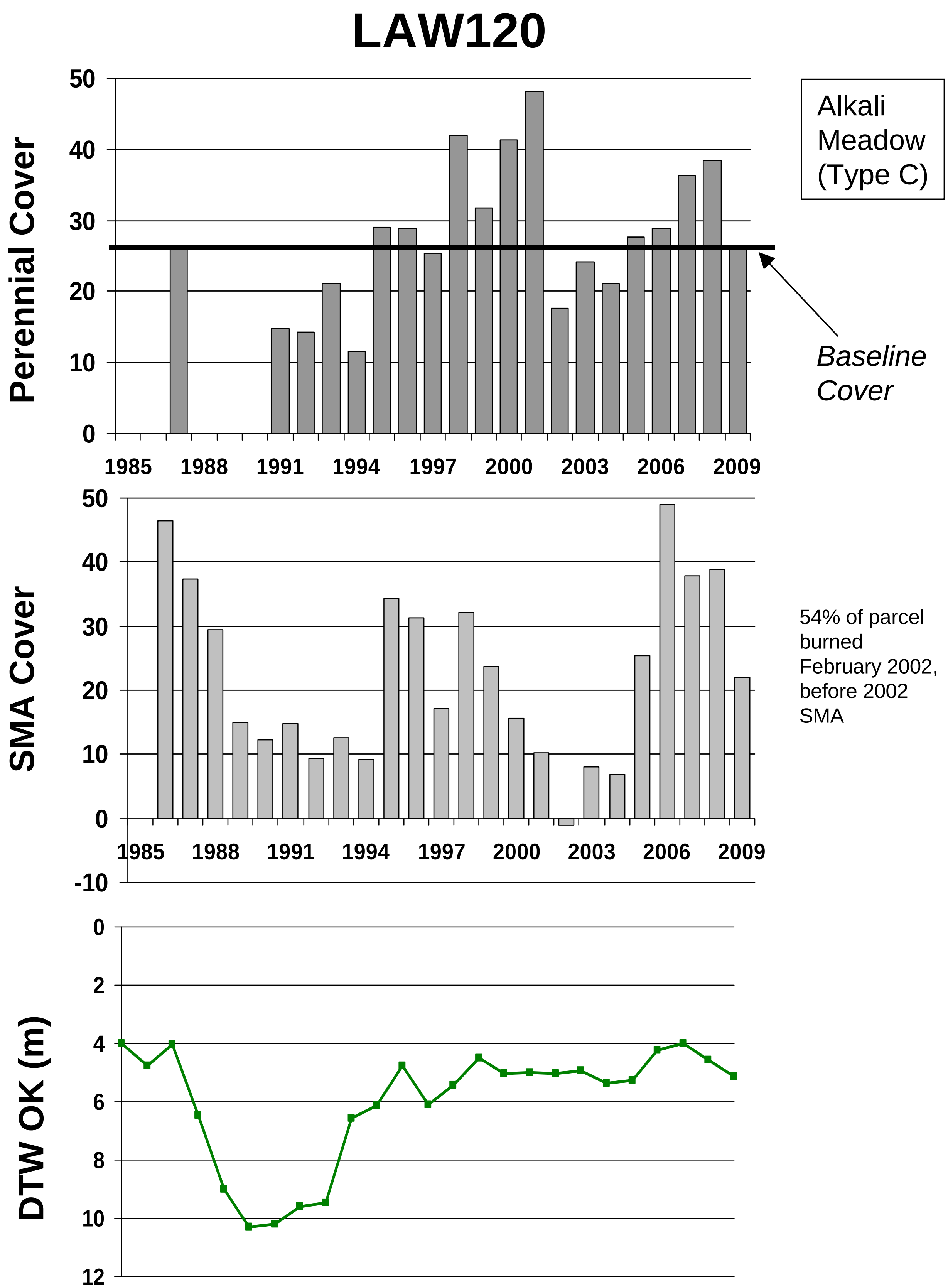


Figure 64. 2009: Wellfield



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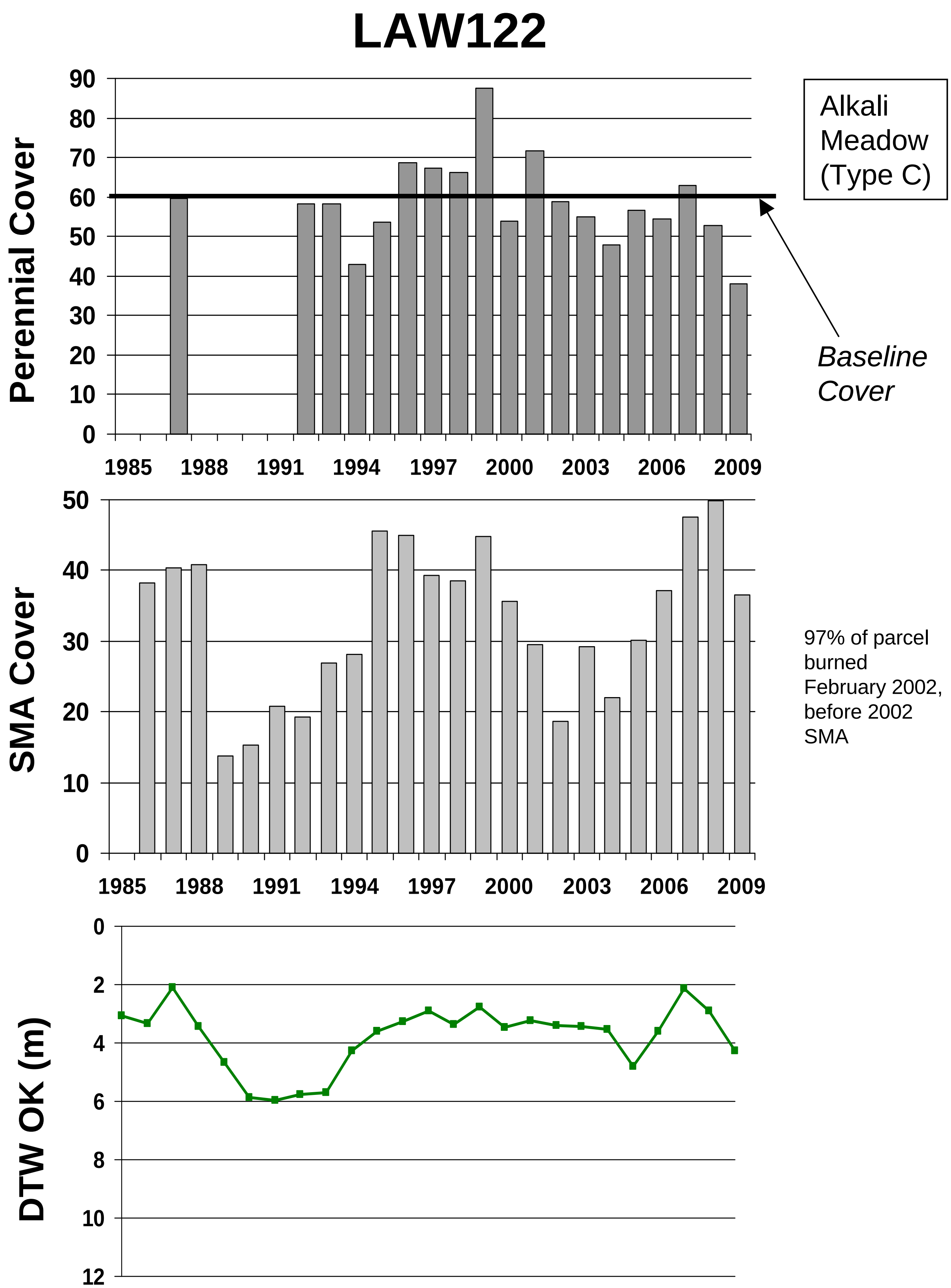

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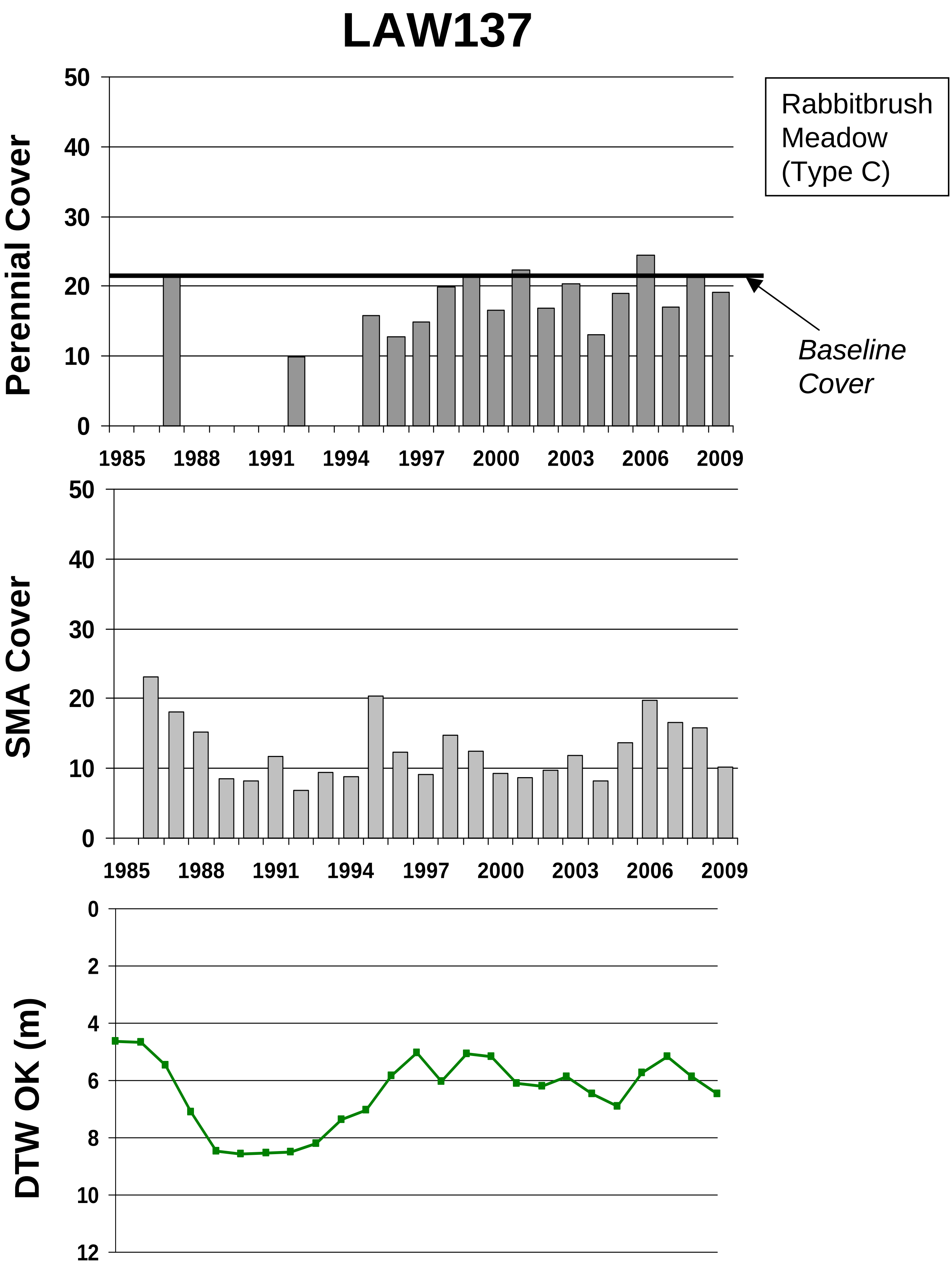

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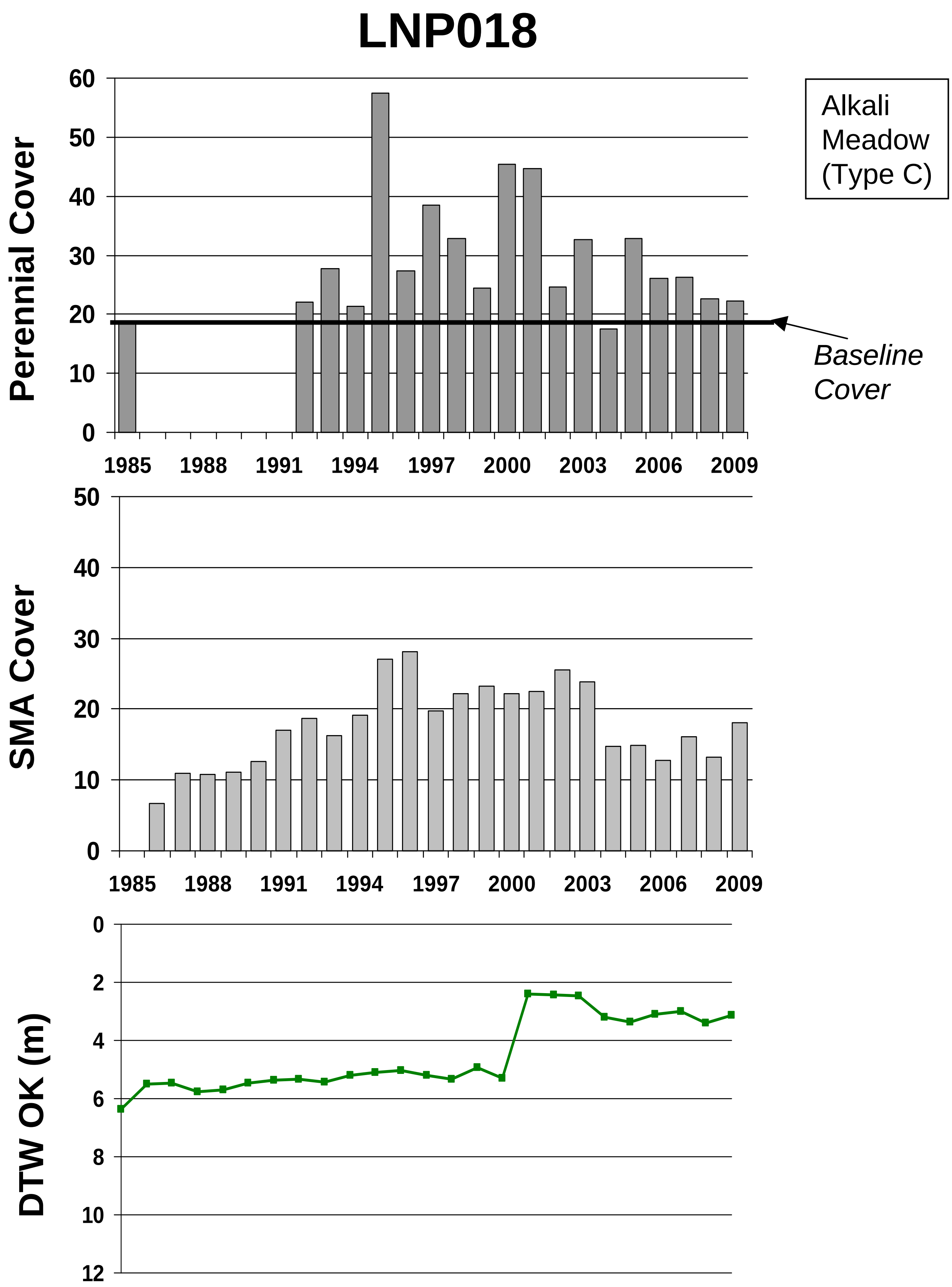

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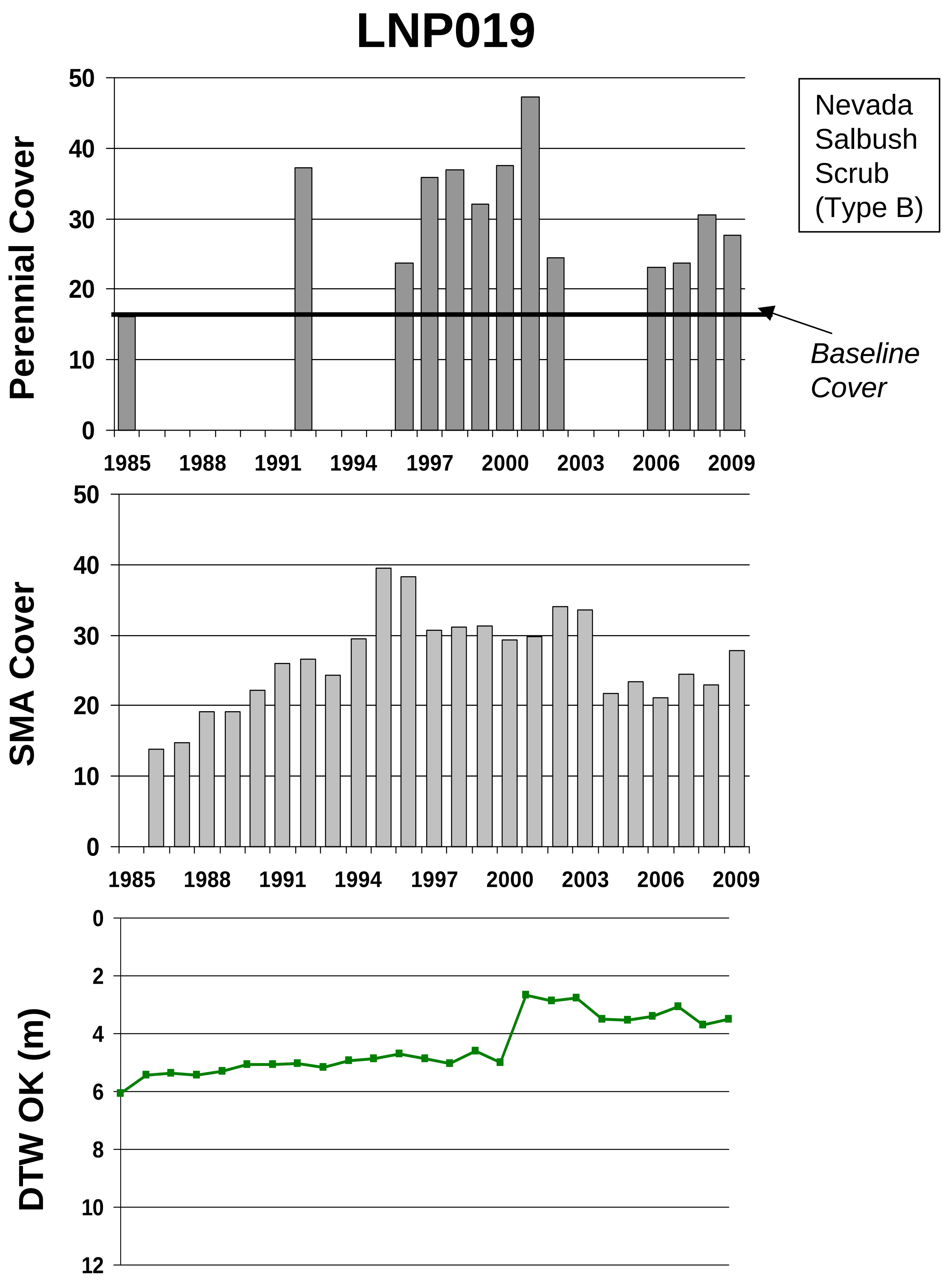

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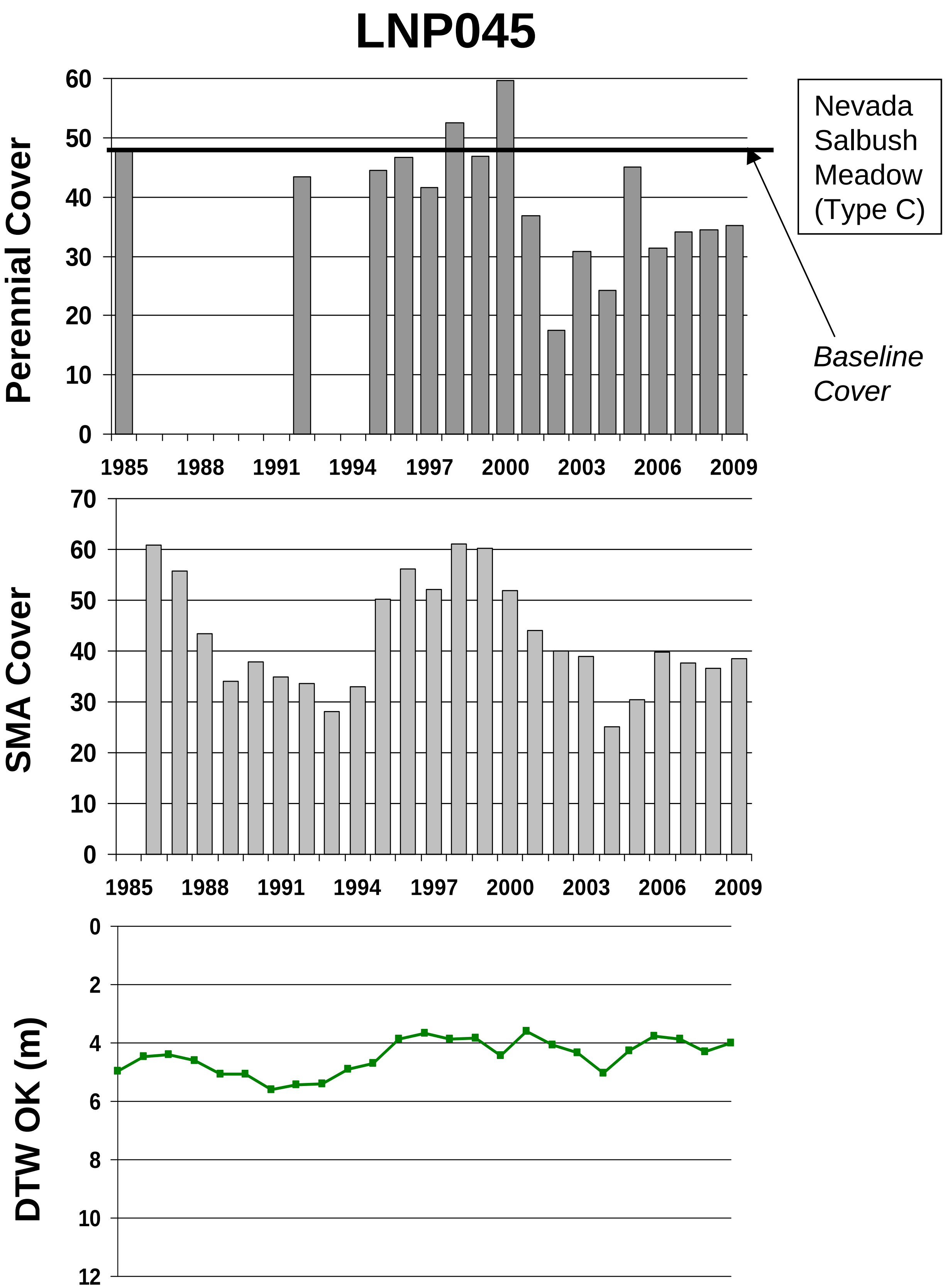

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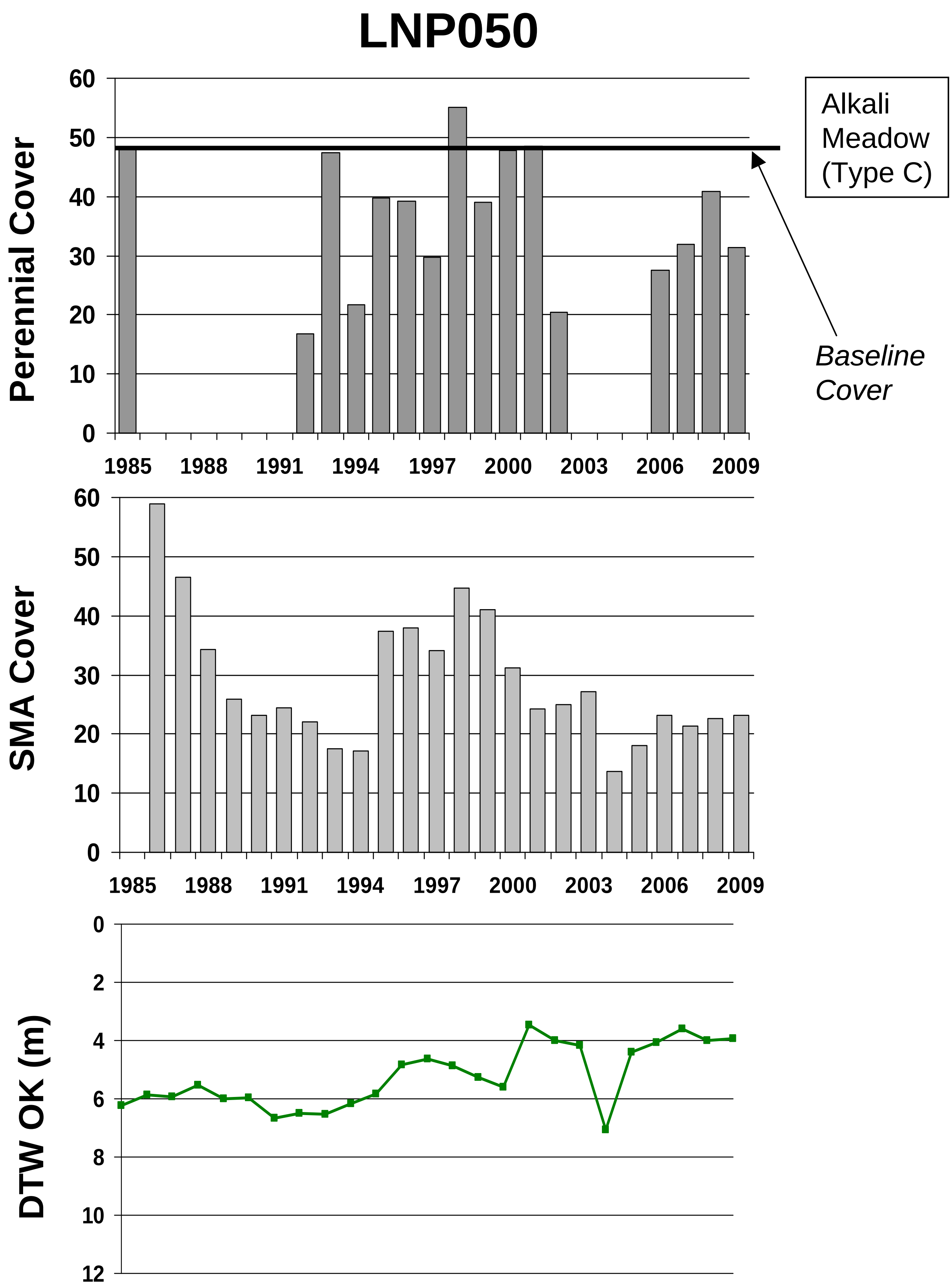

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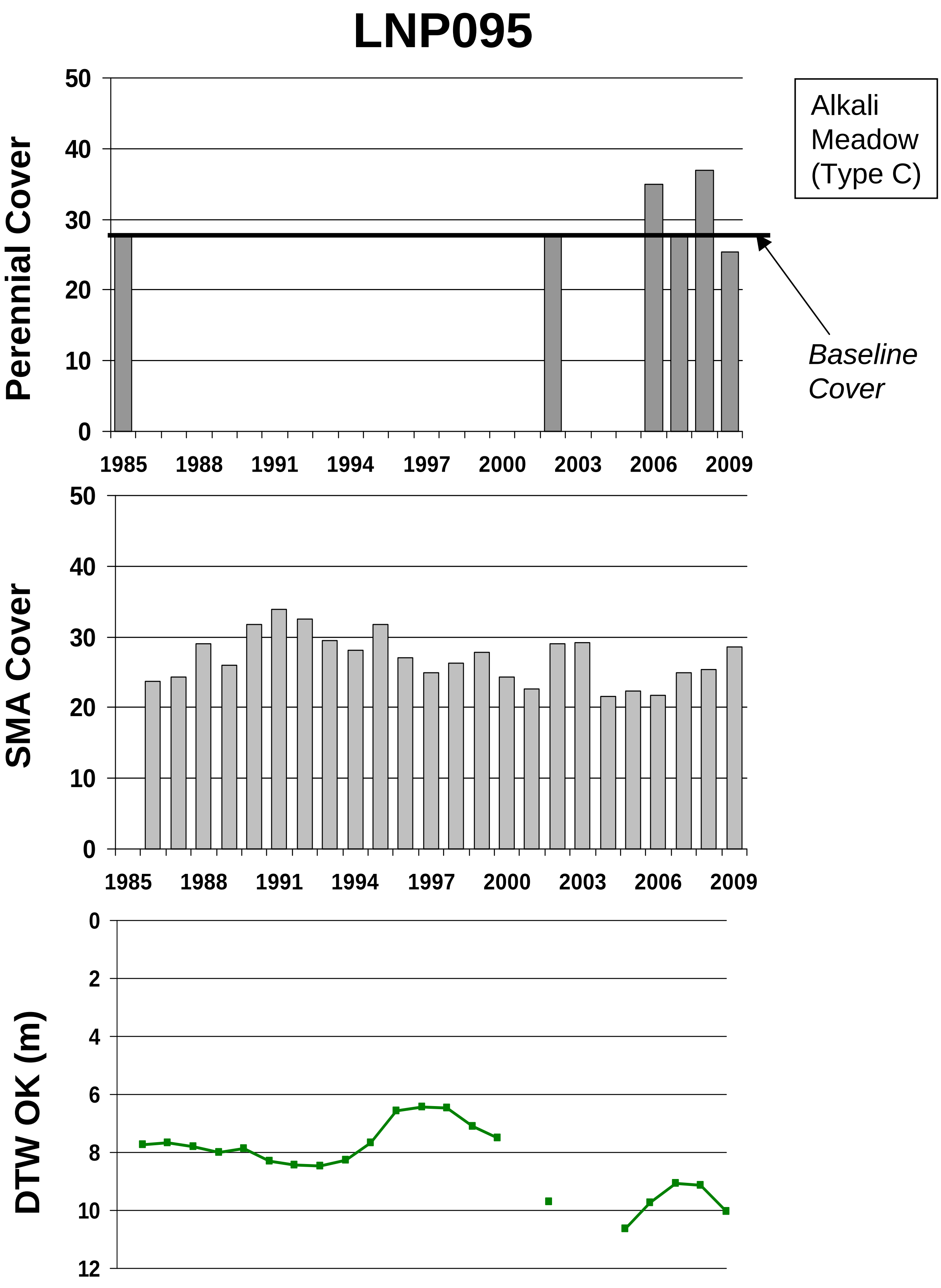

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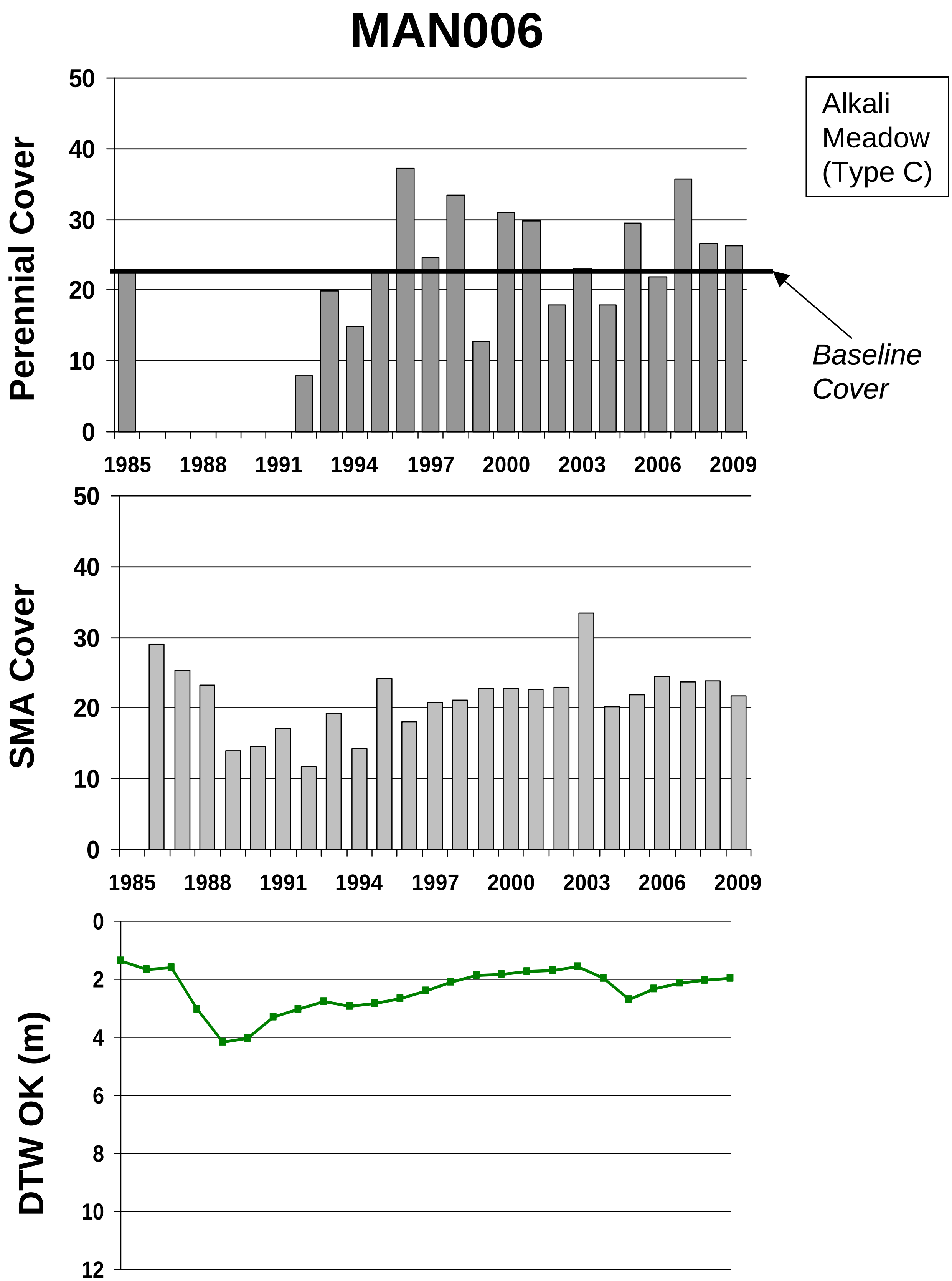

Figure 73. 2009: Wellfield

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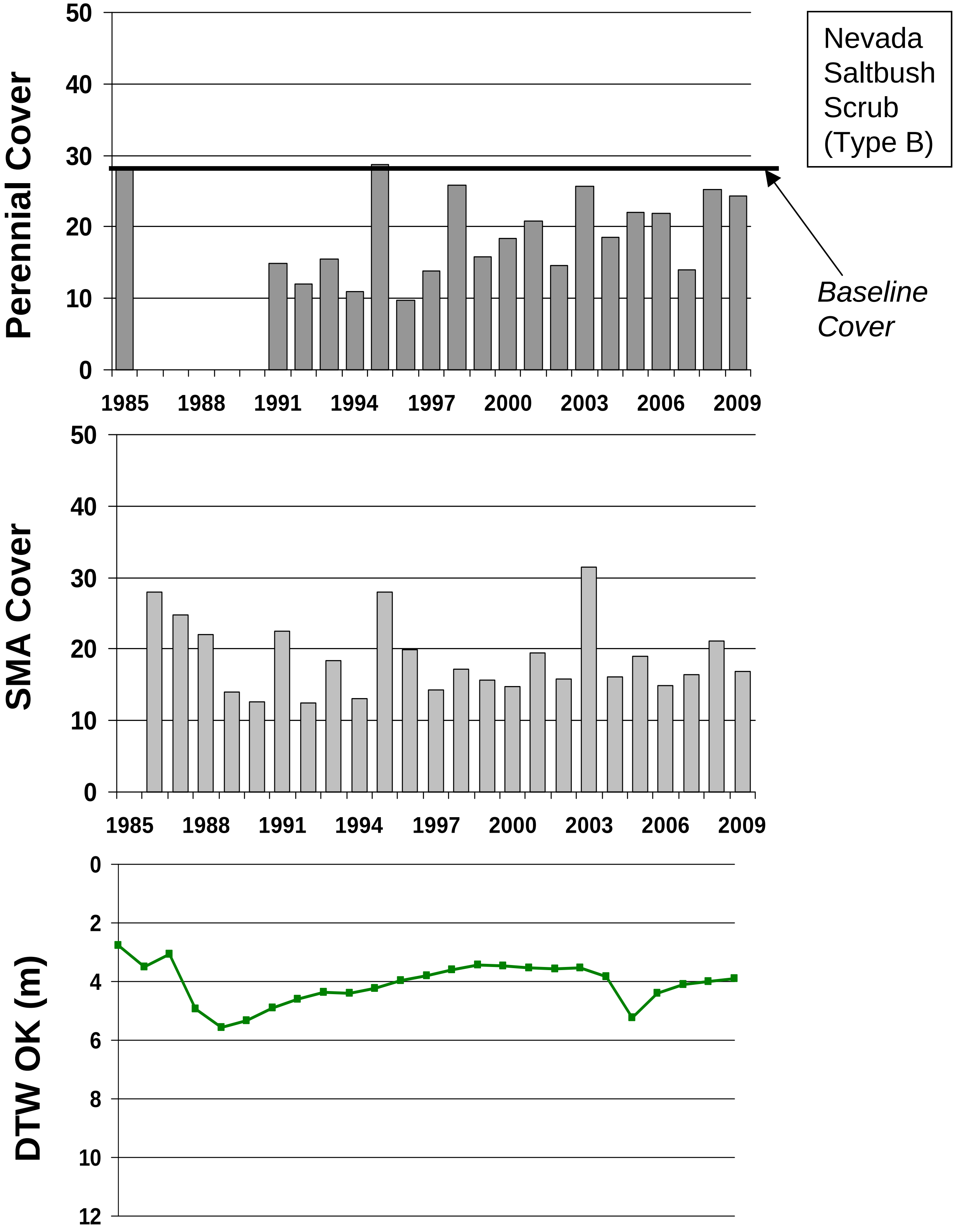

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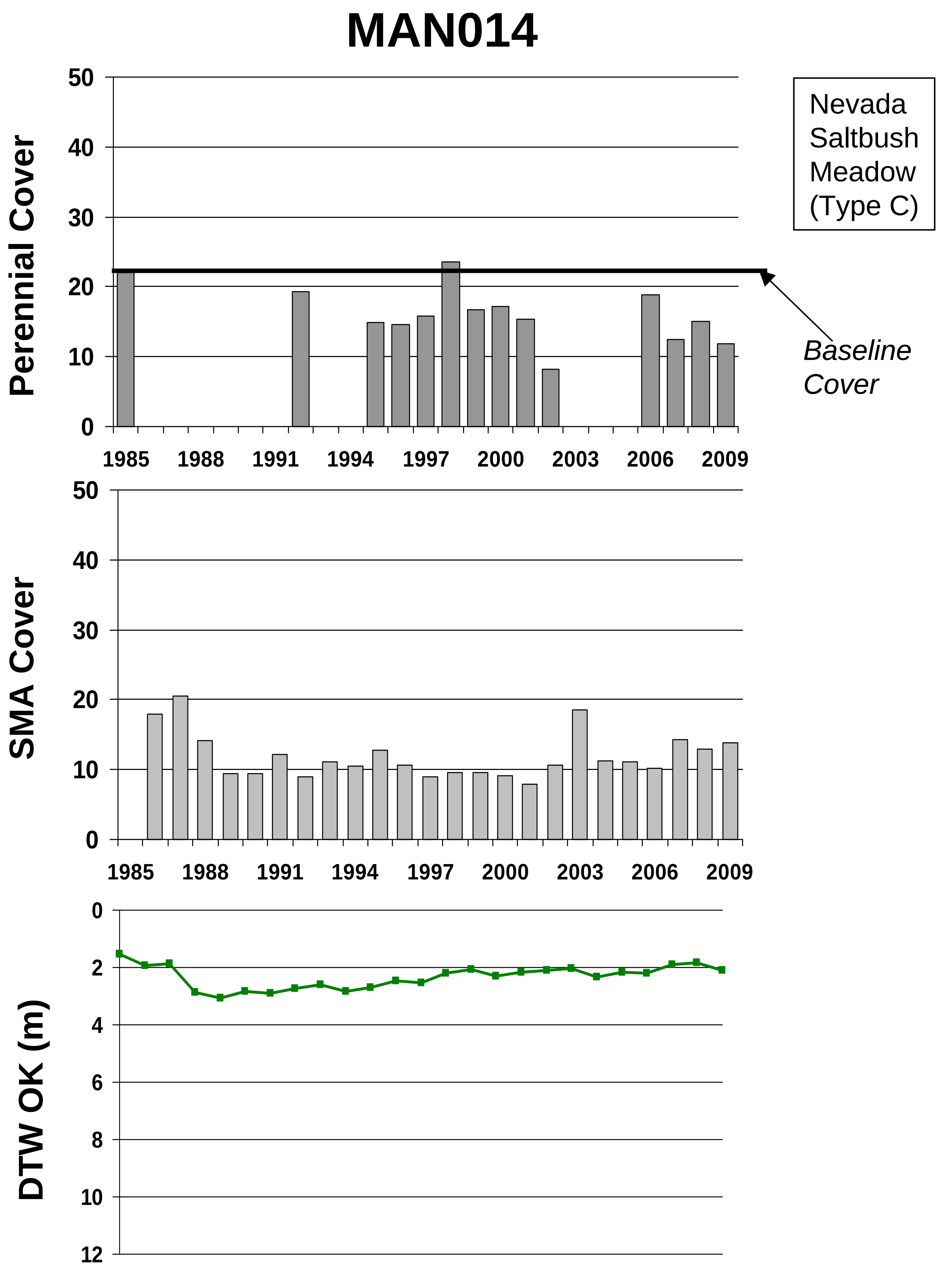

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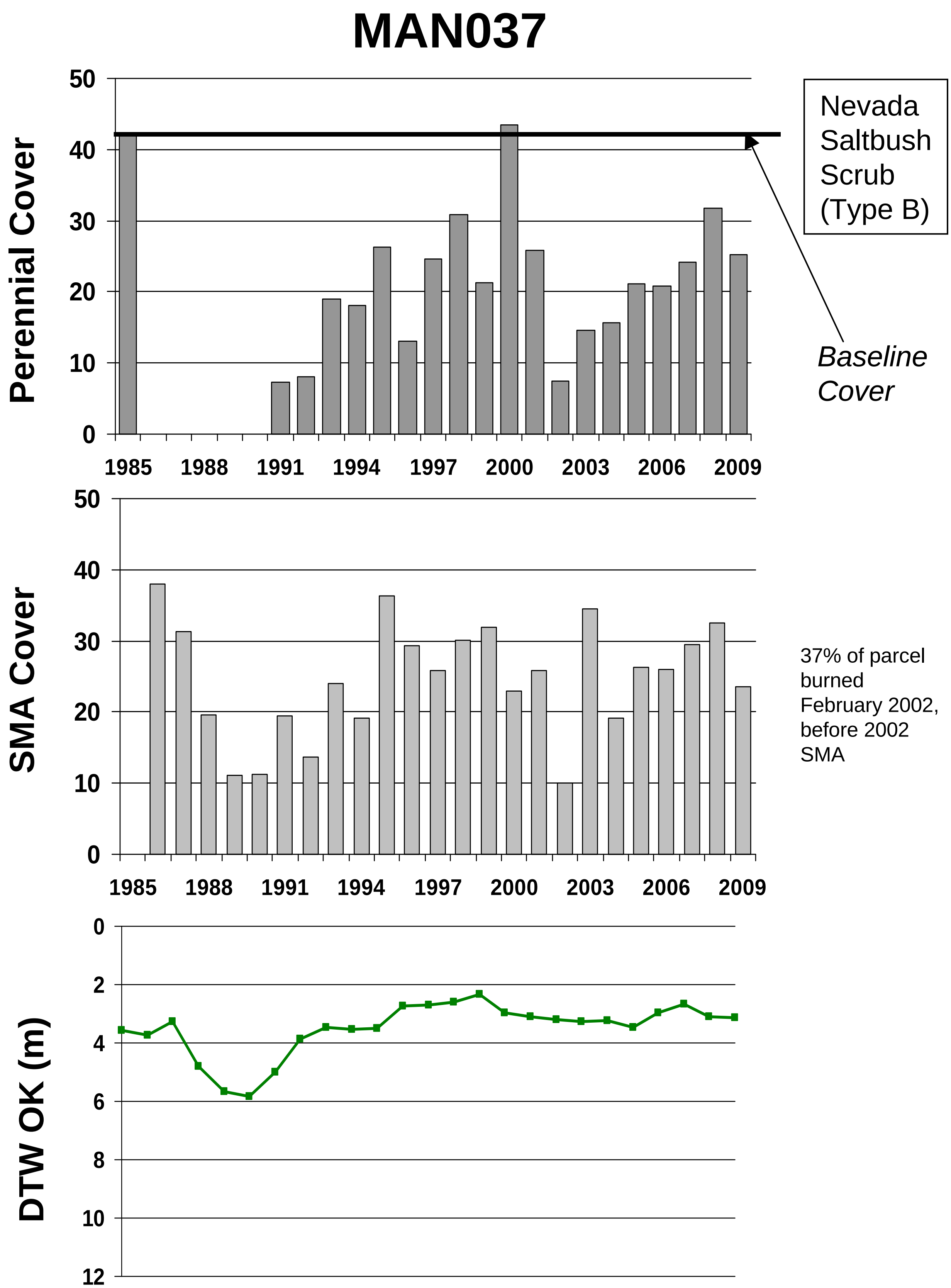

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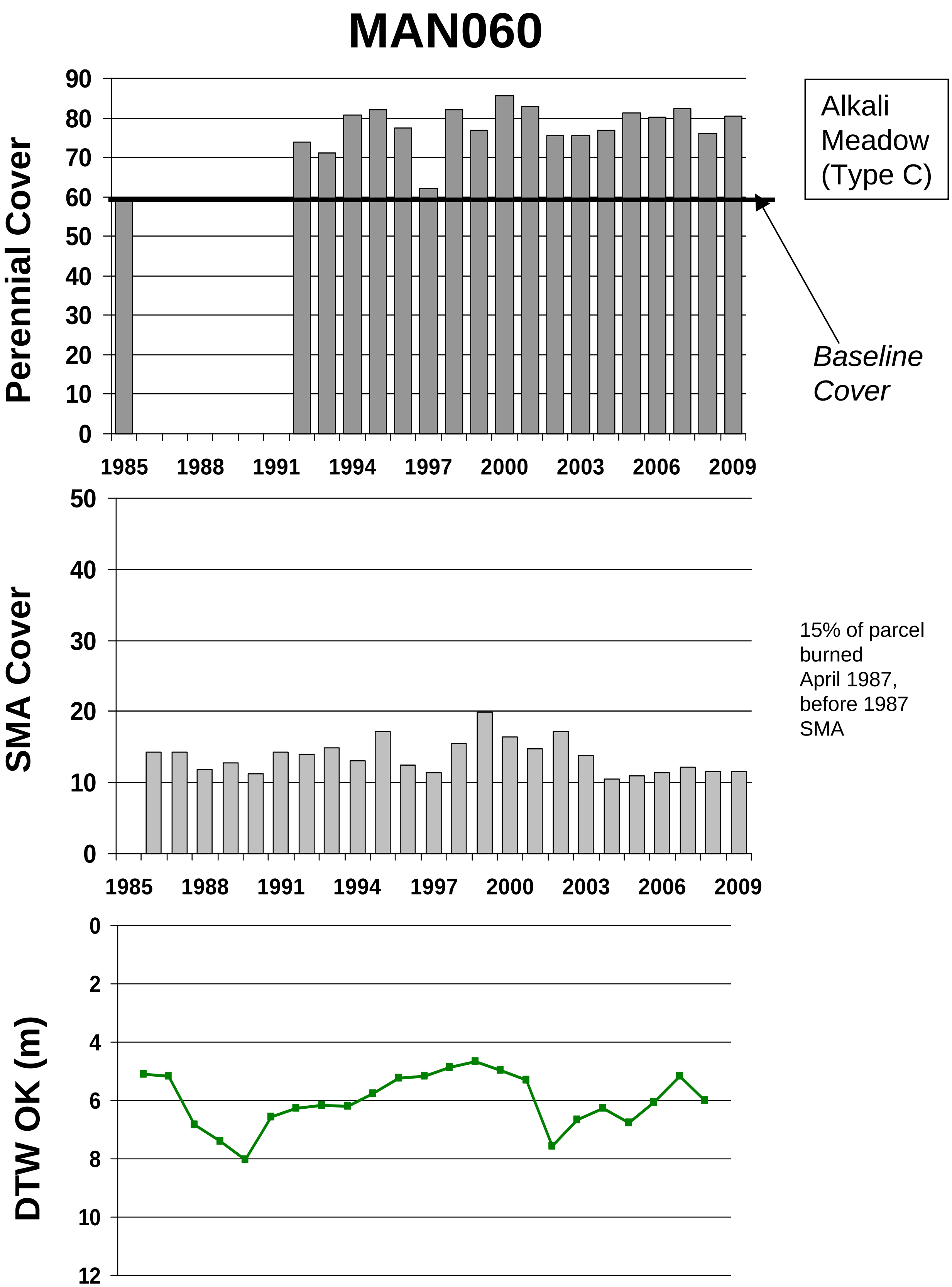

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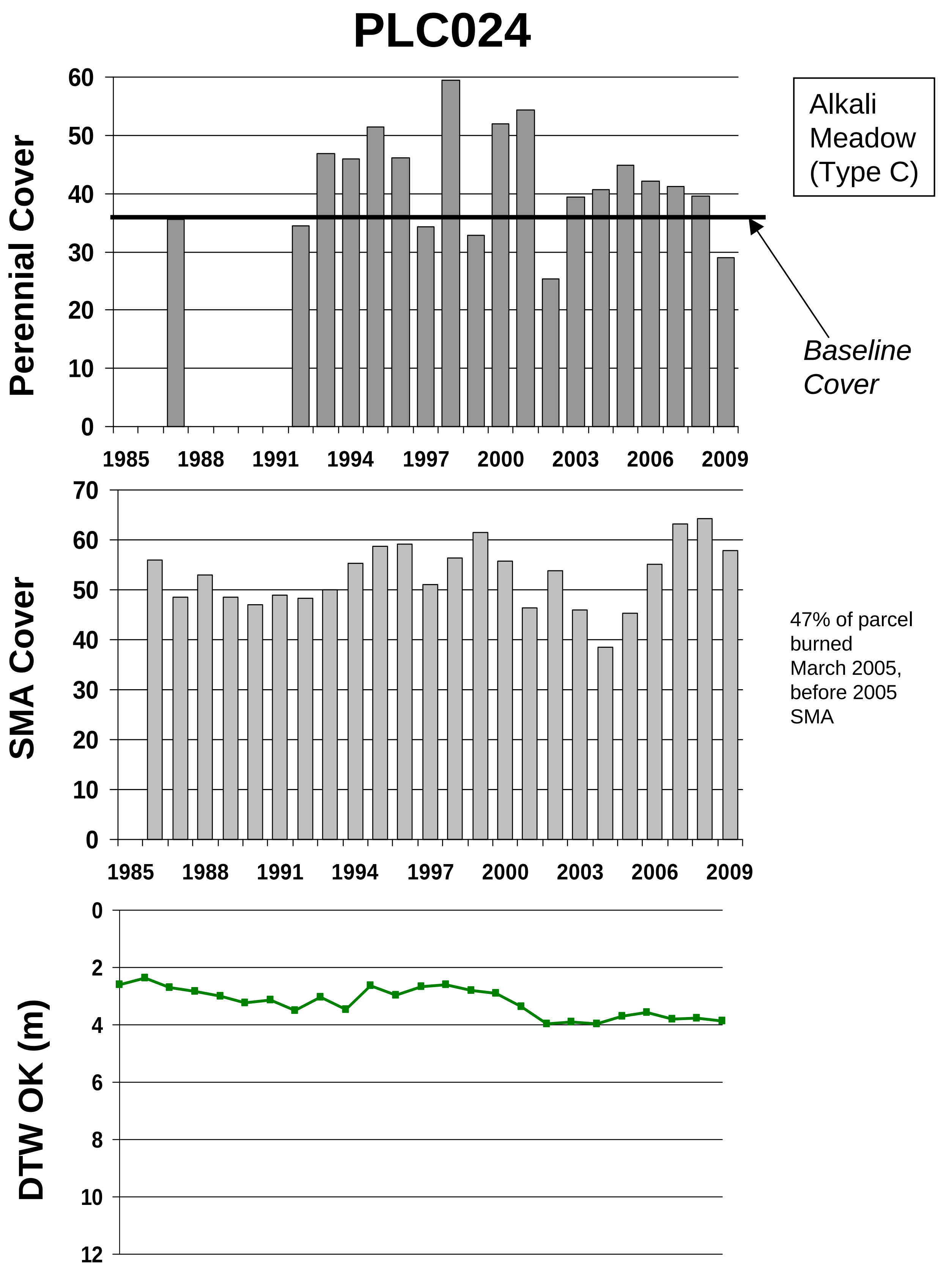

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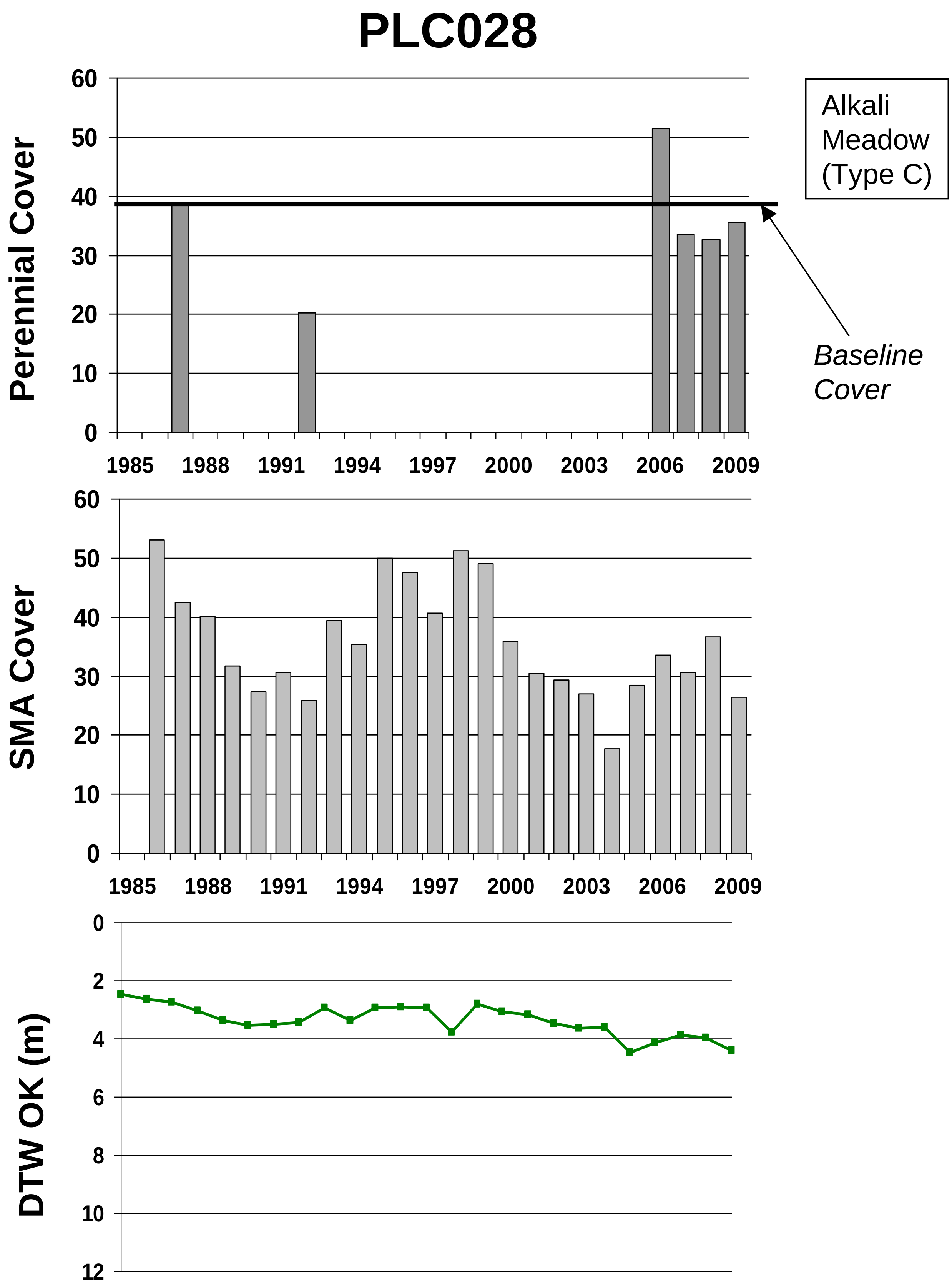

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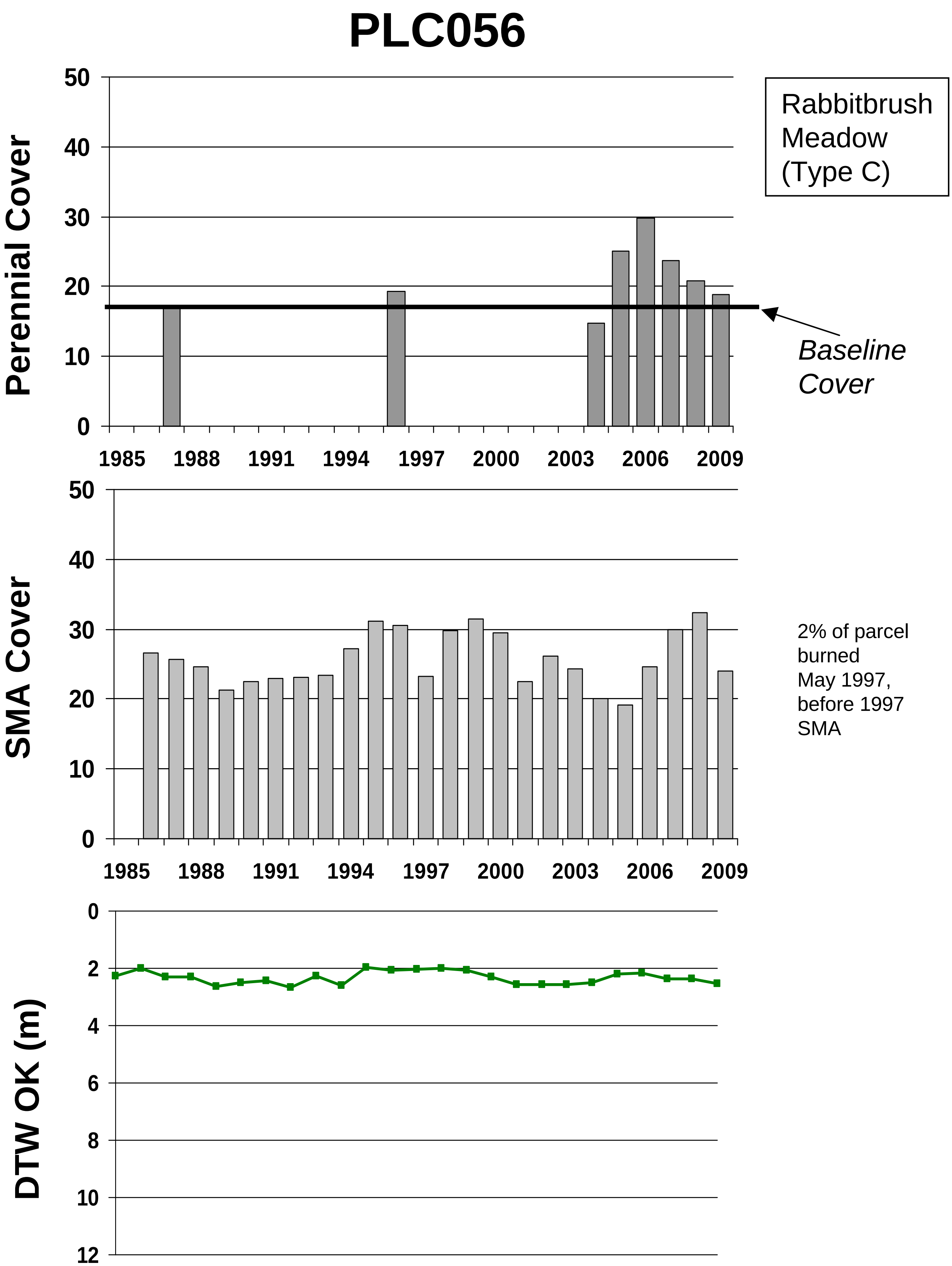

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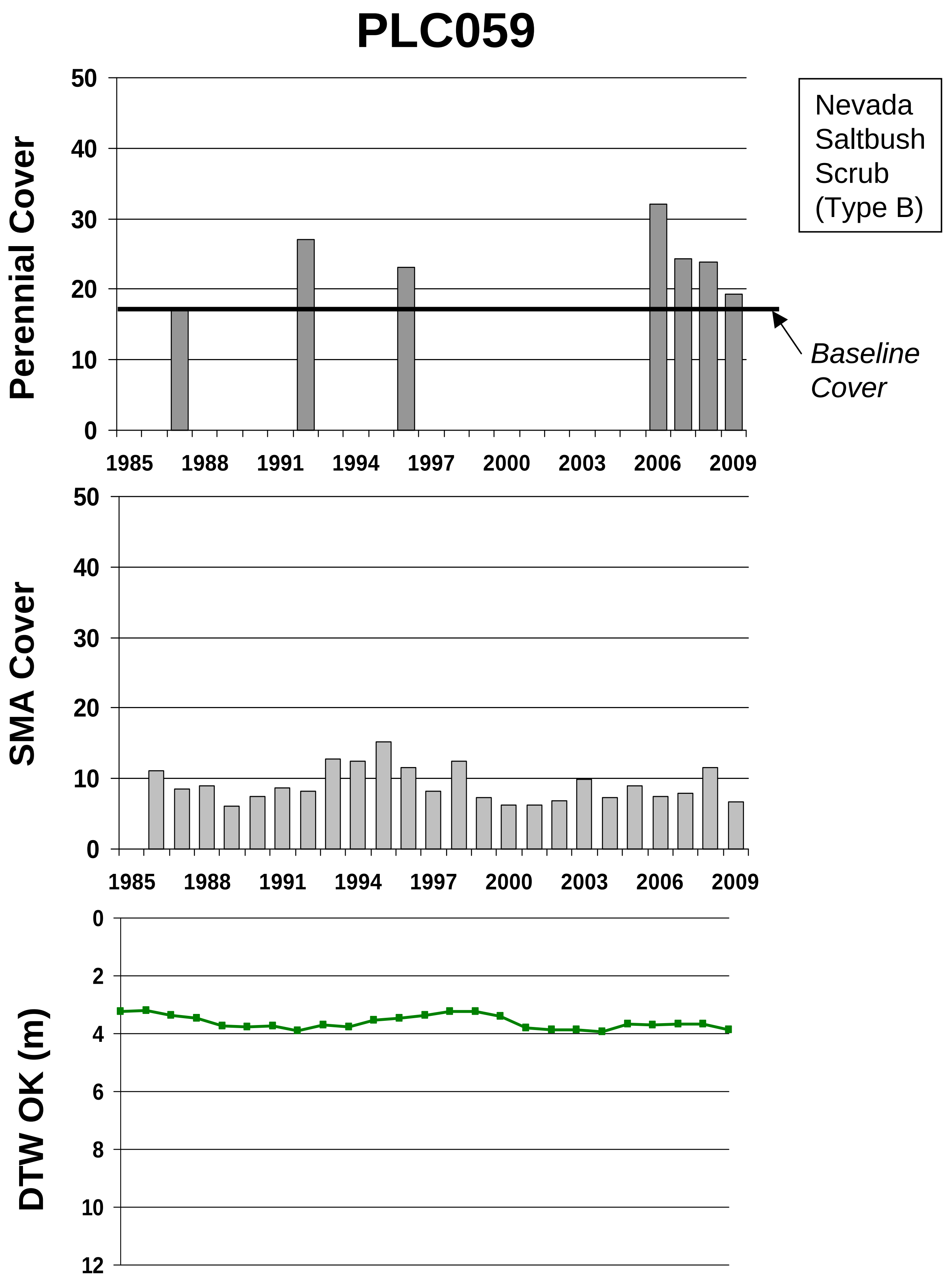

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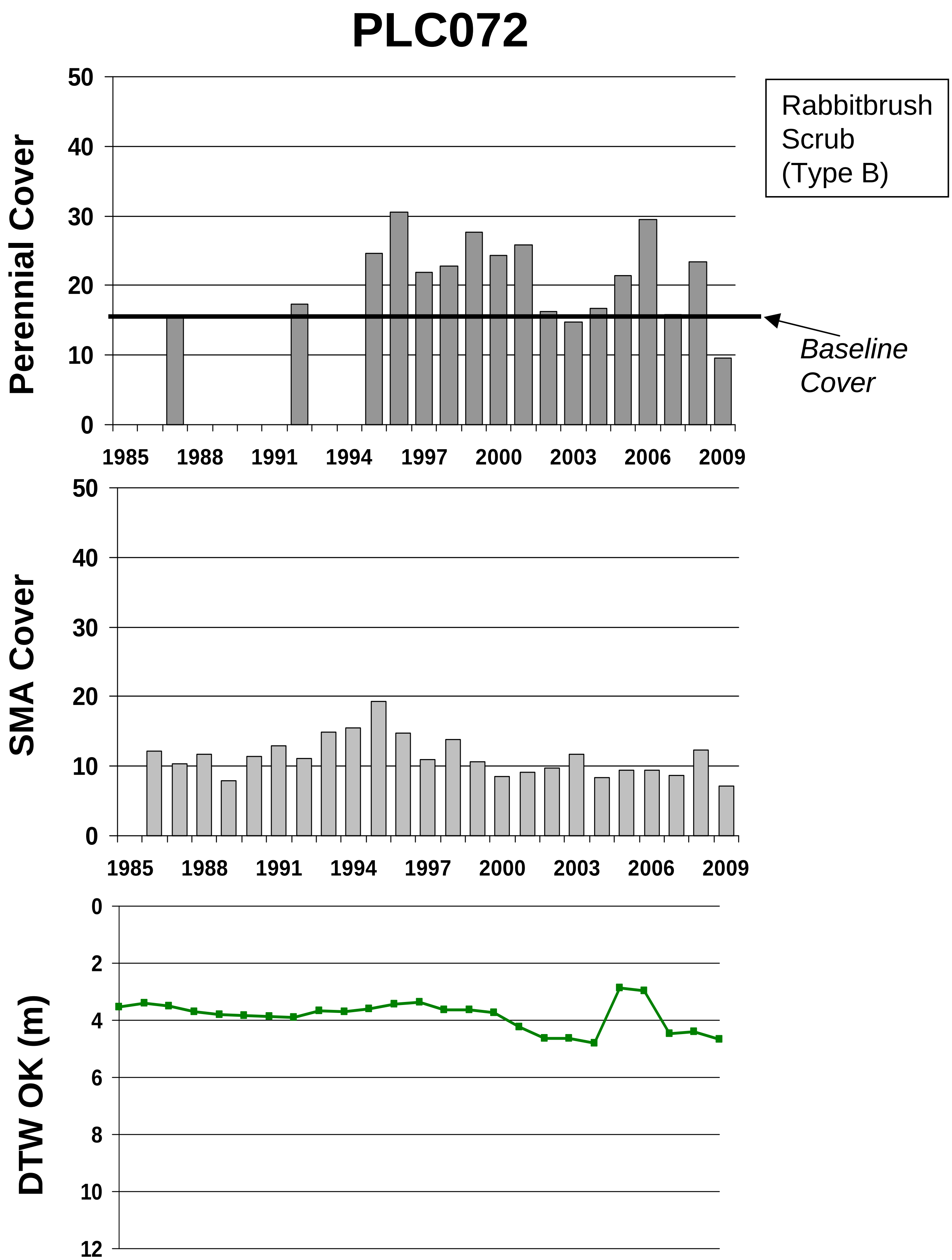

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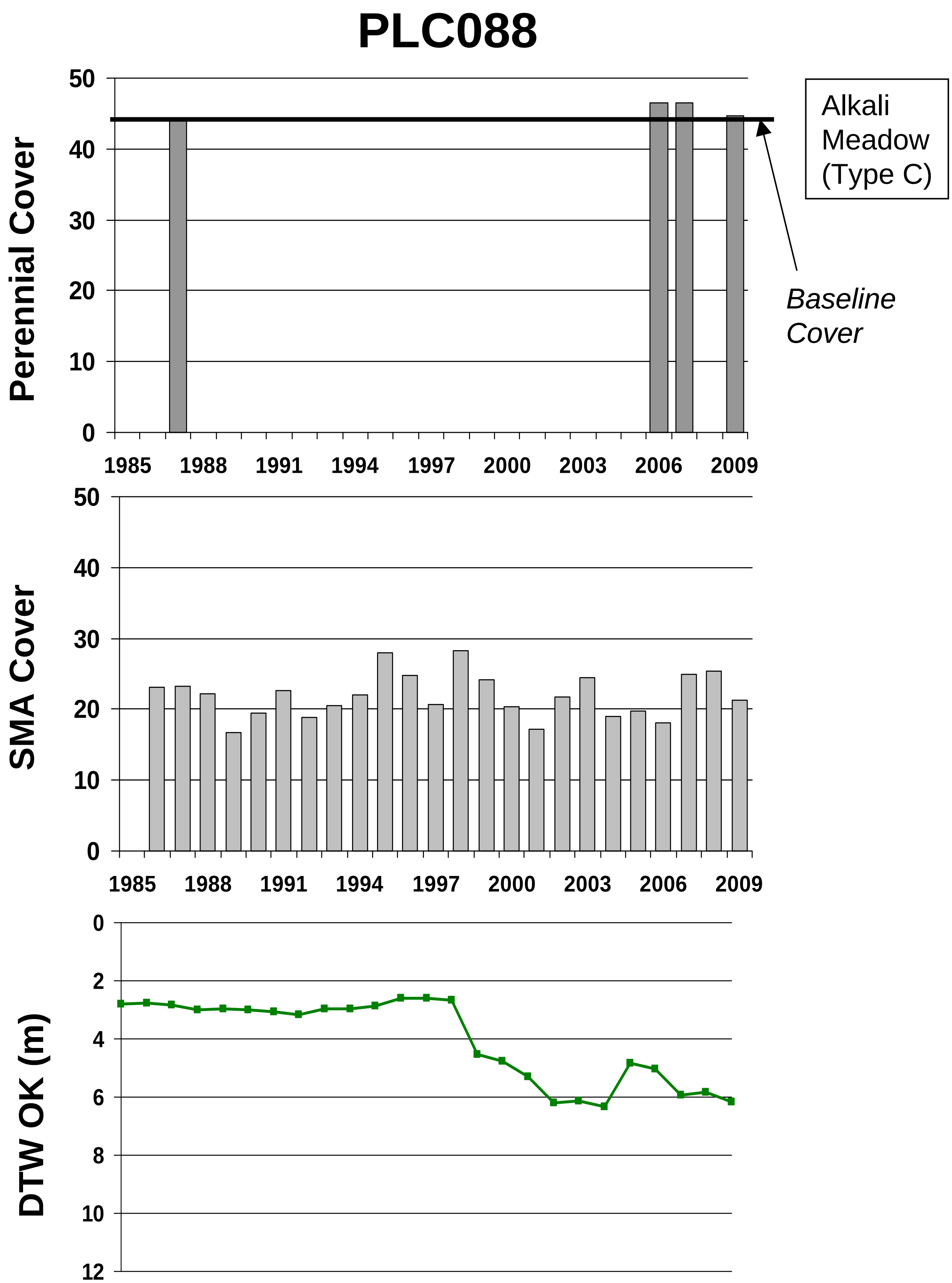

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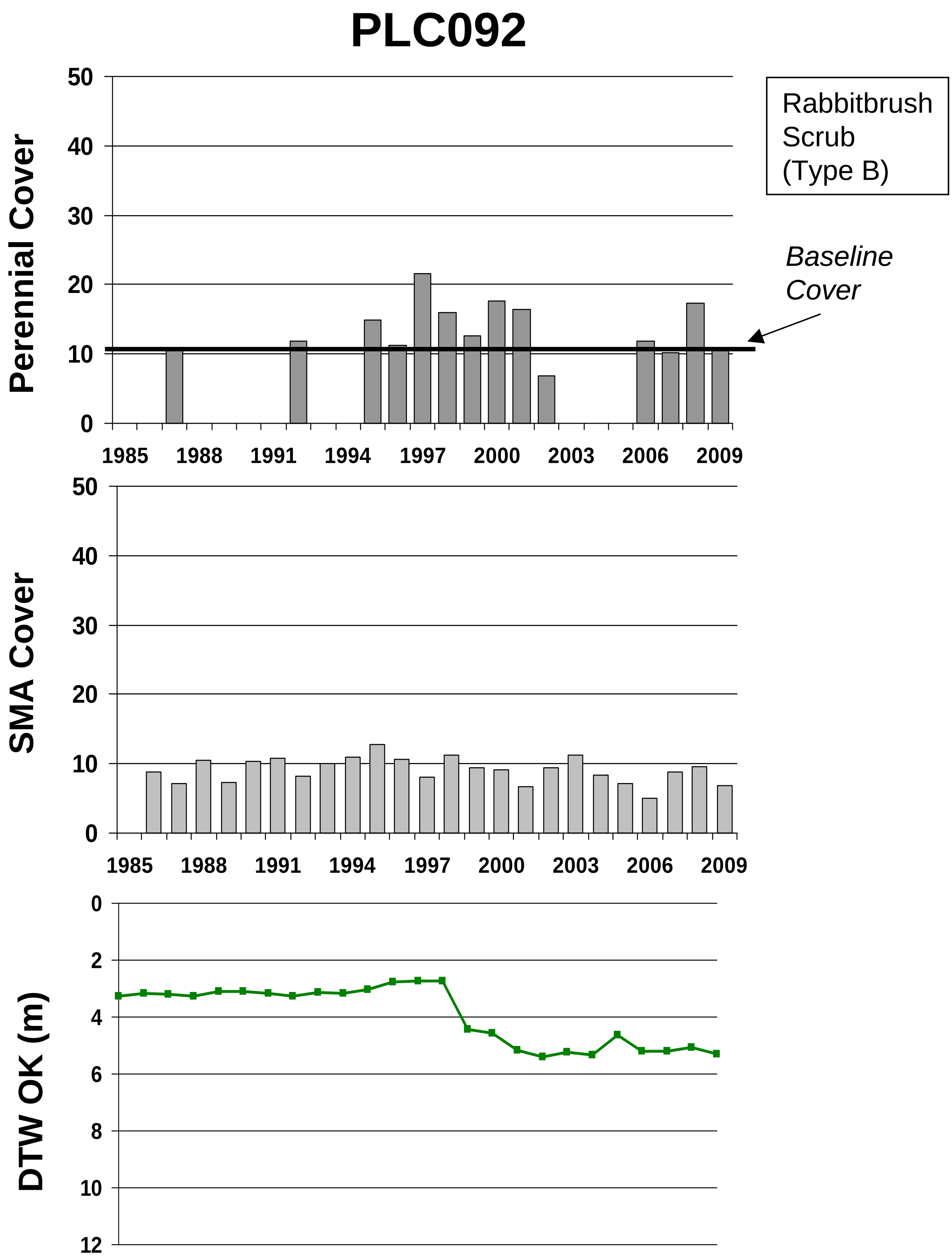

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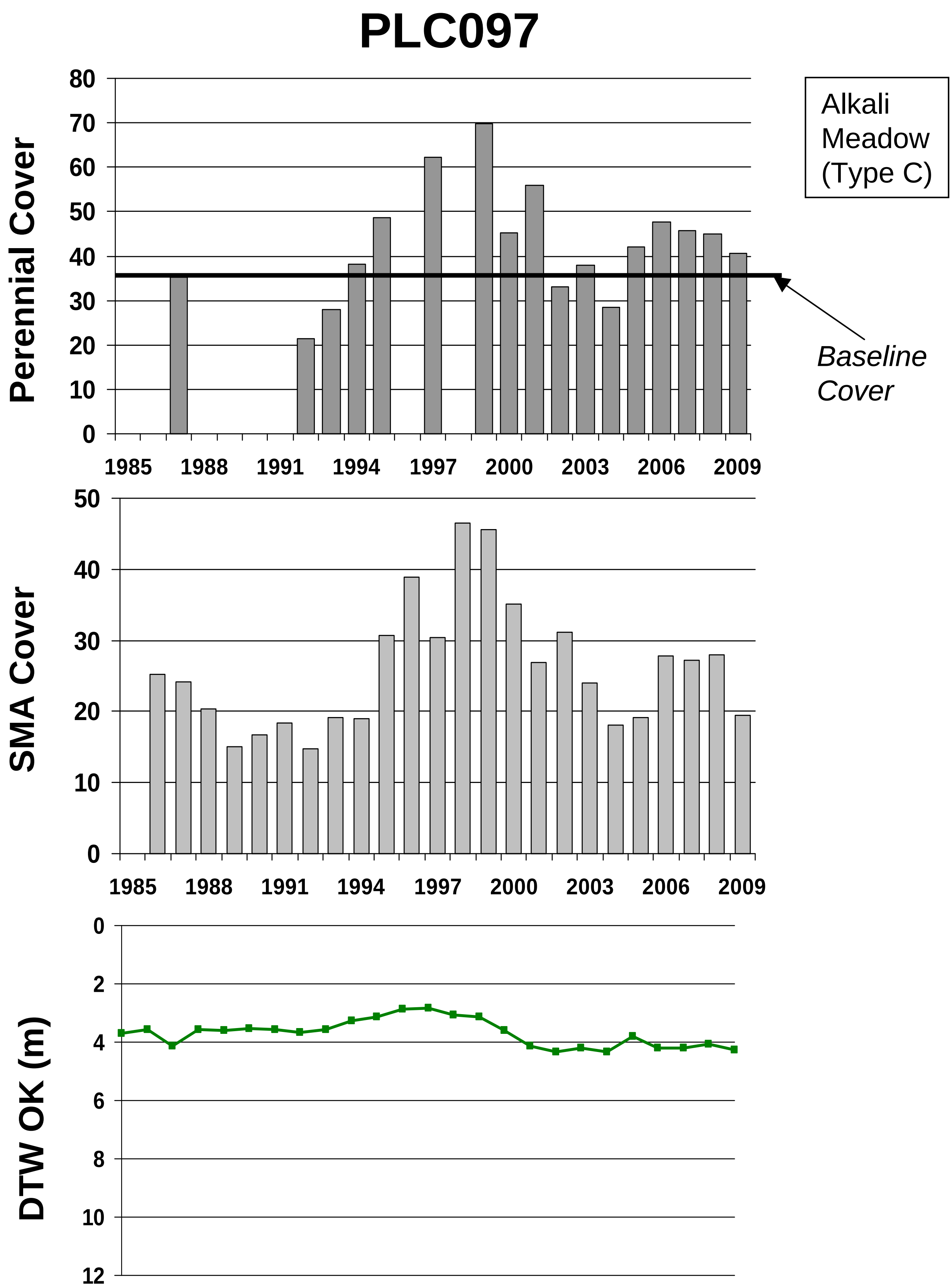

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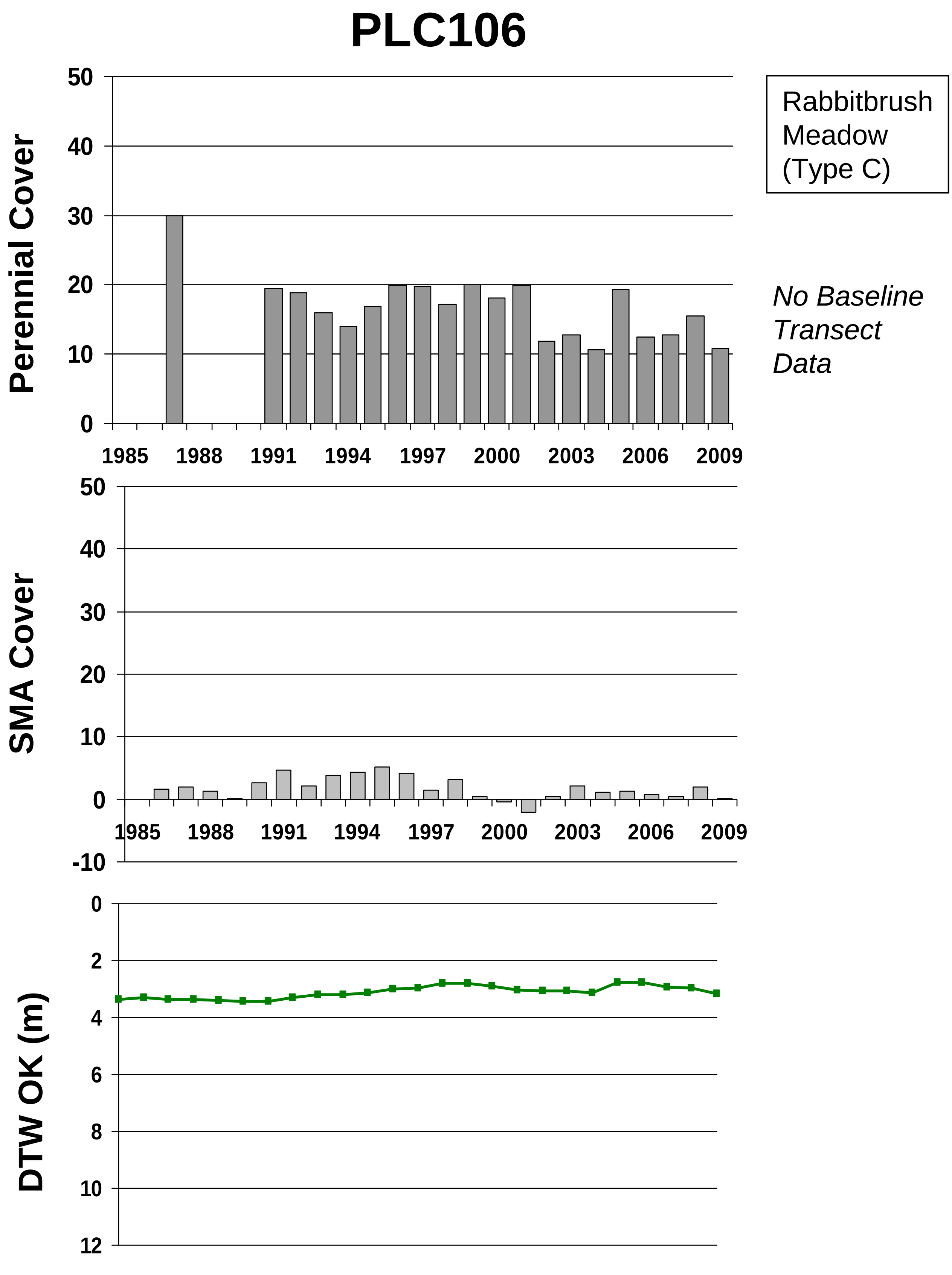

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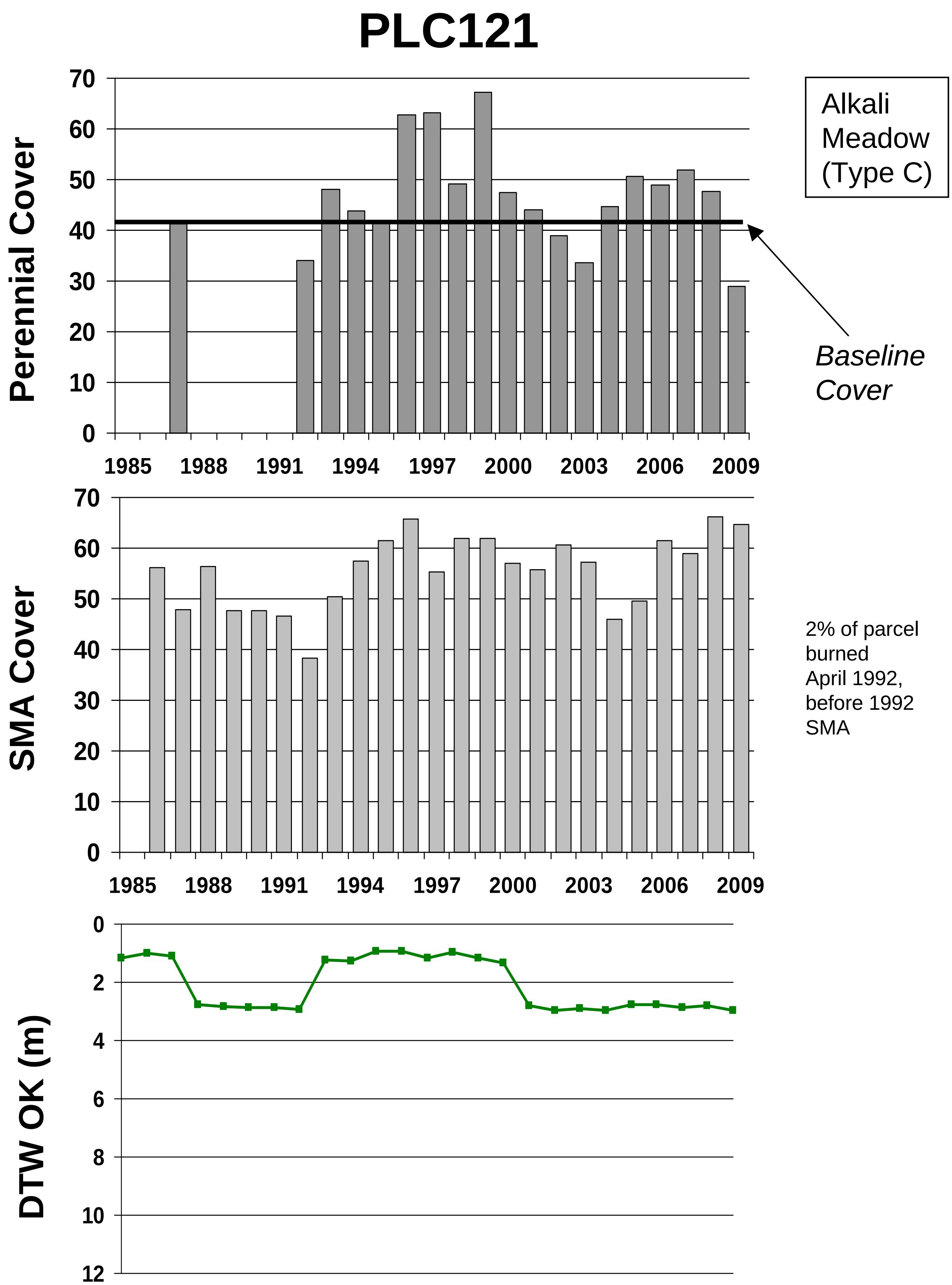

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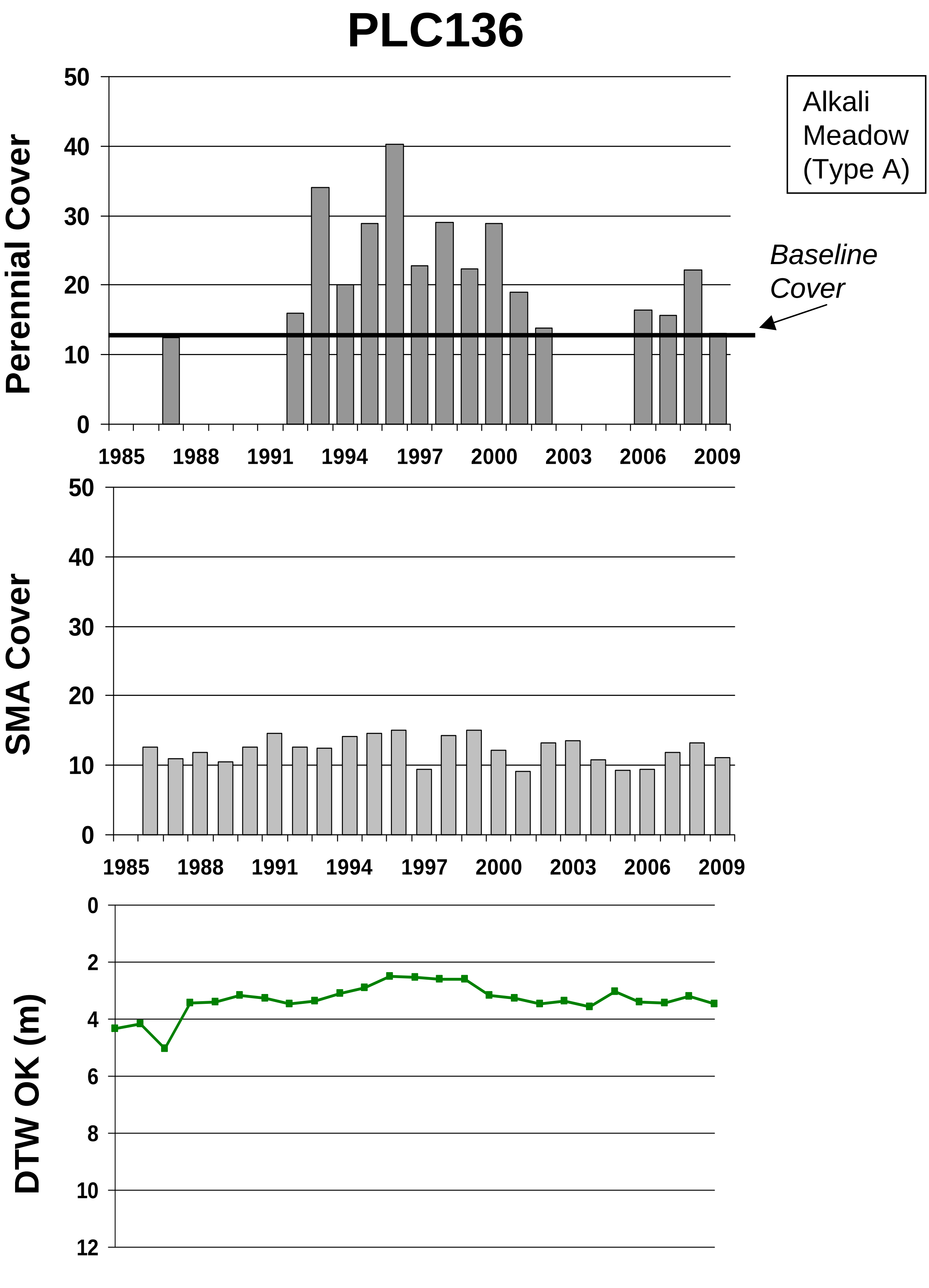

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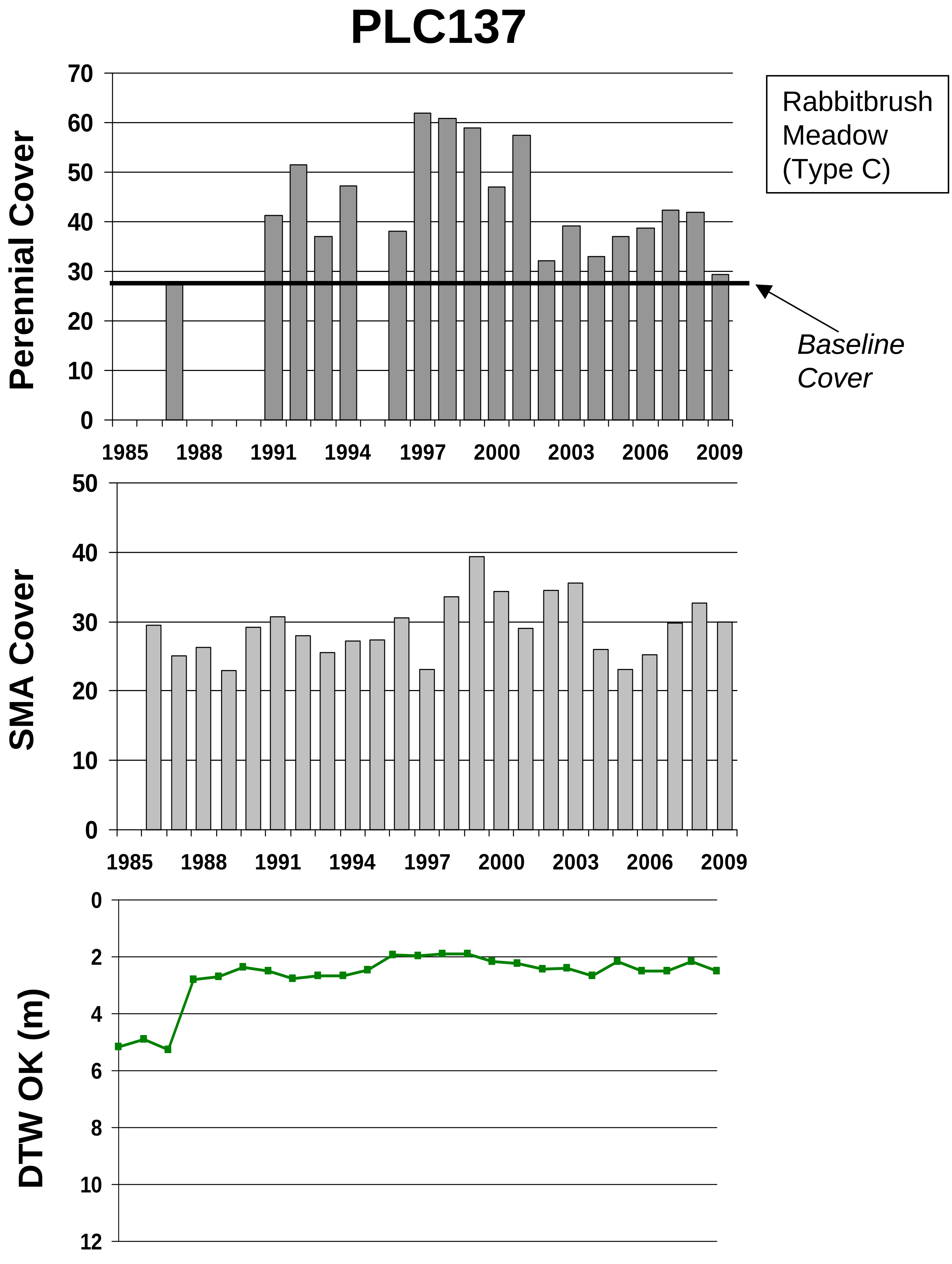

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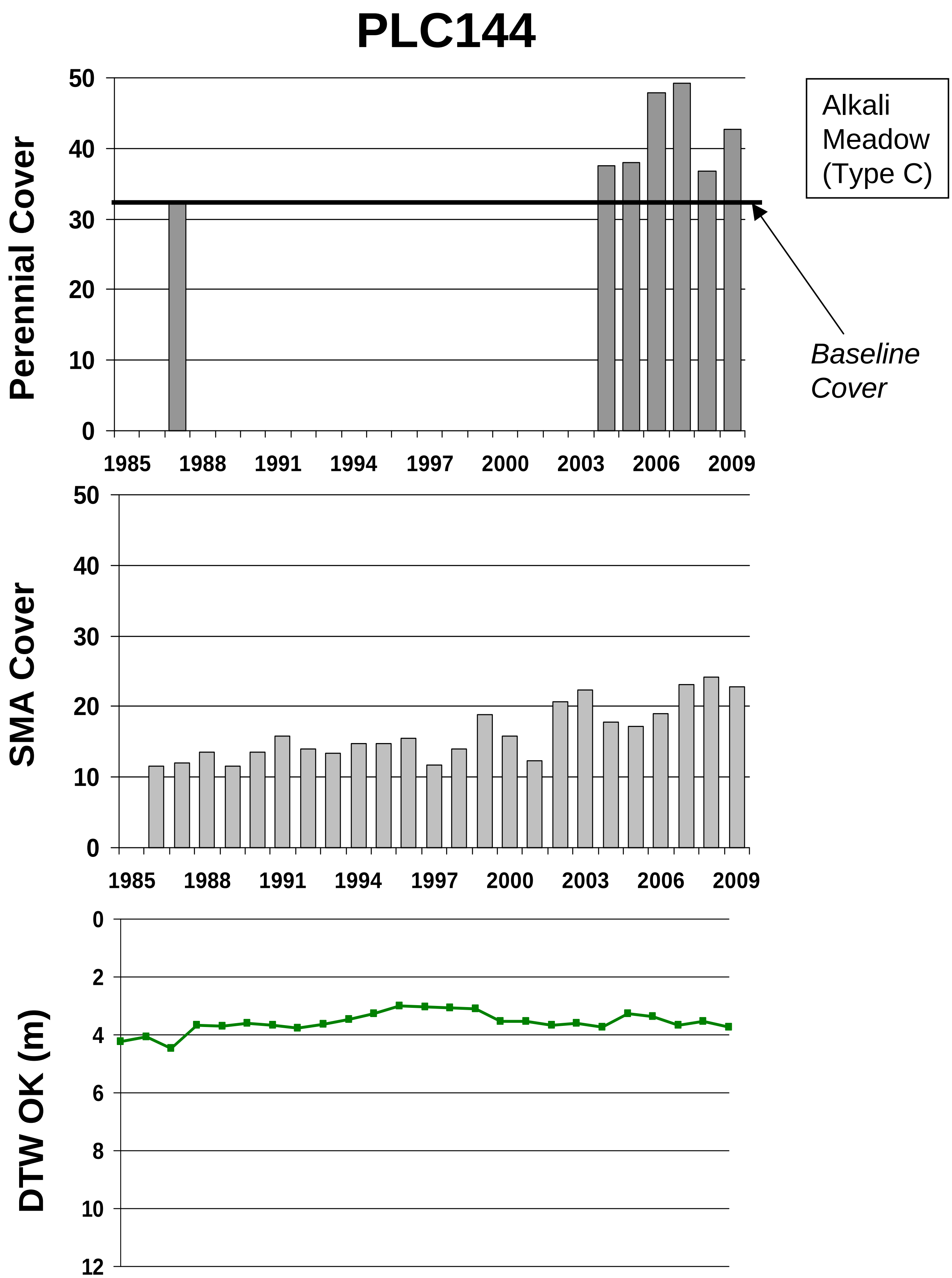

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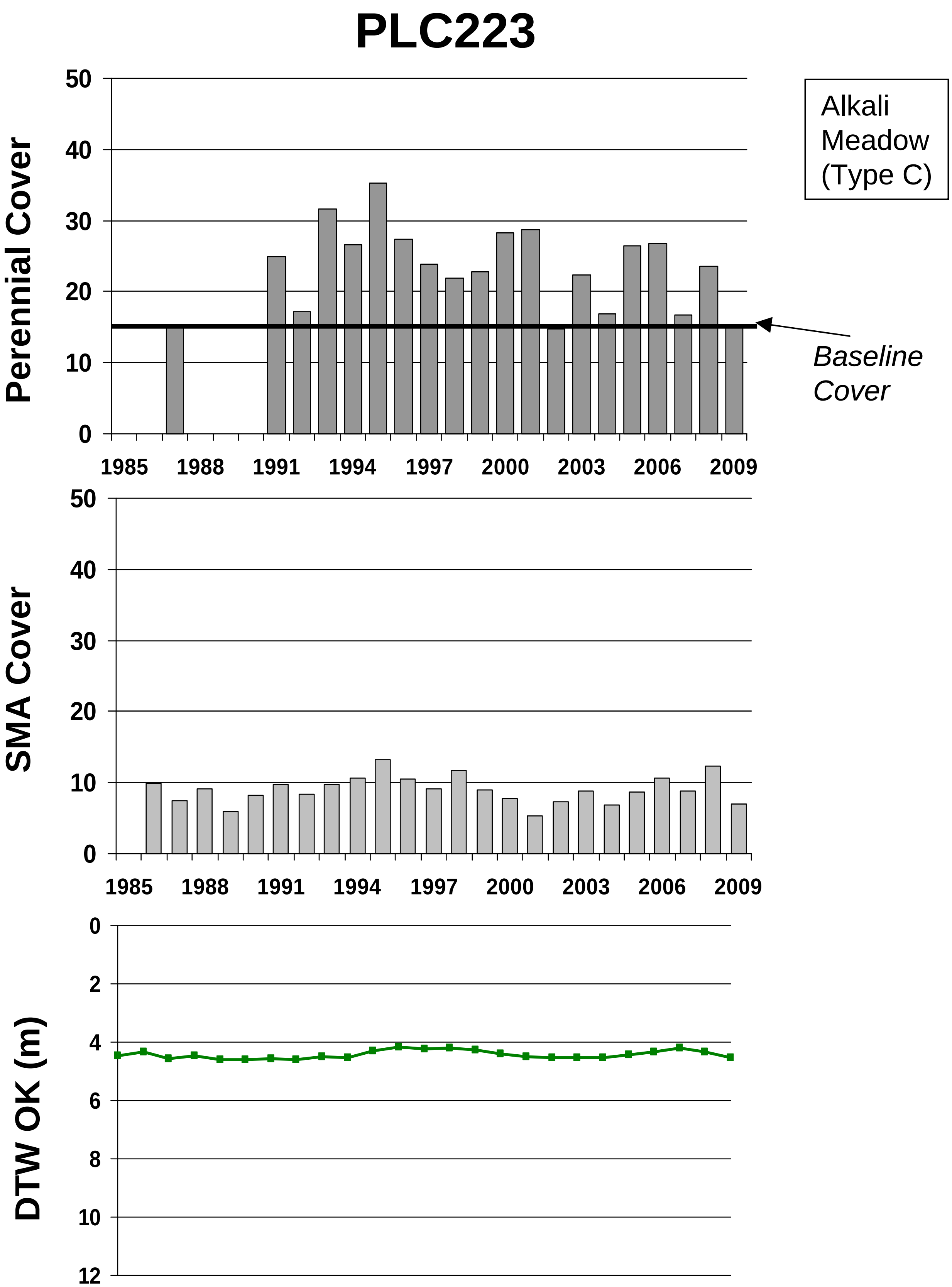

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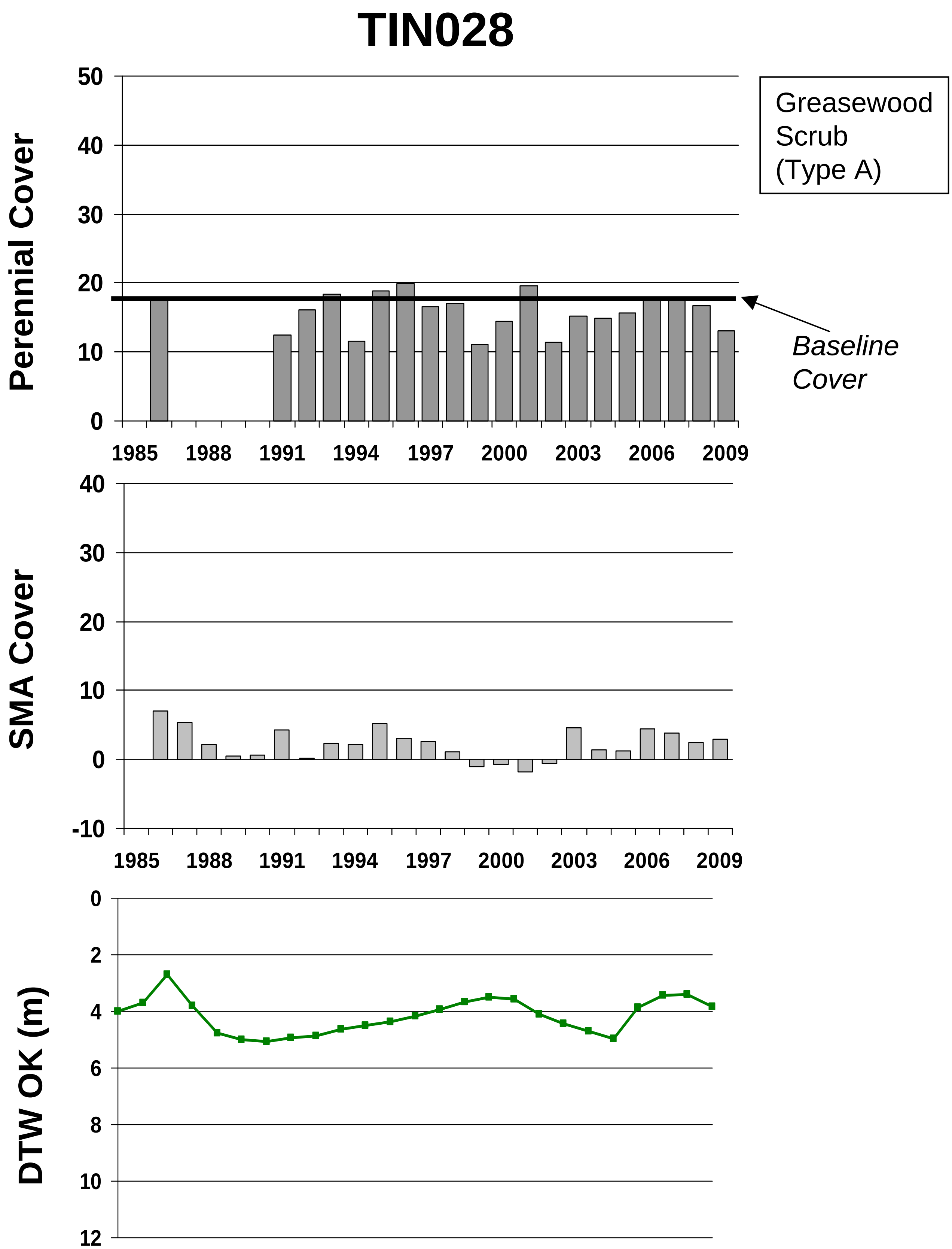
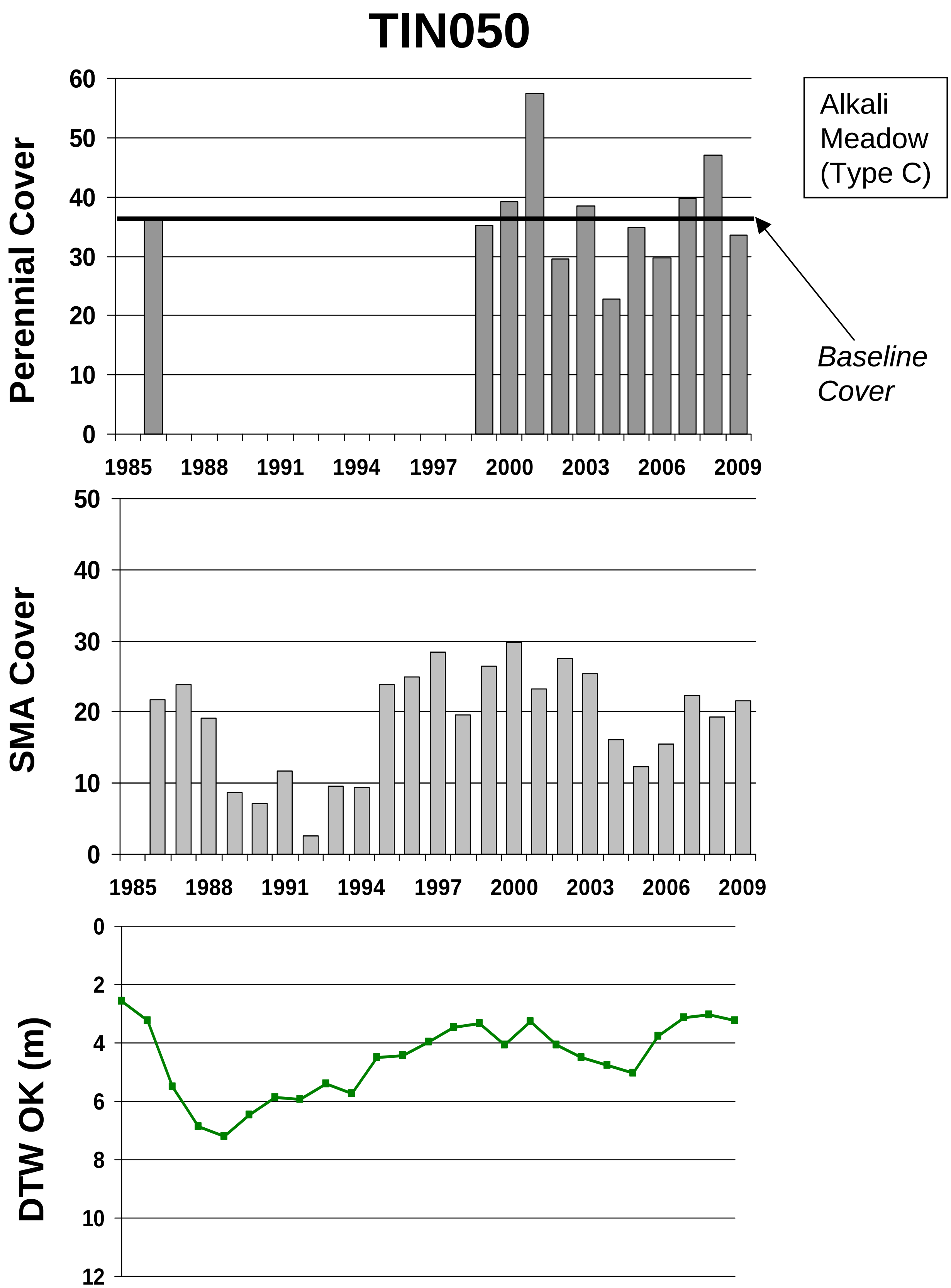


Figure 92. 2009: Wellfield



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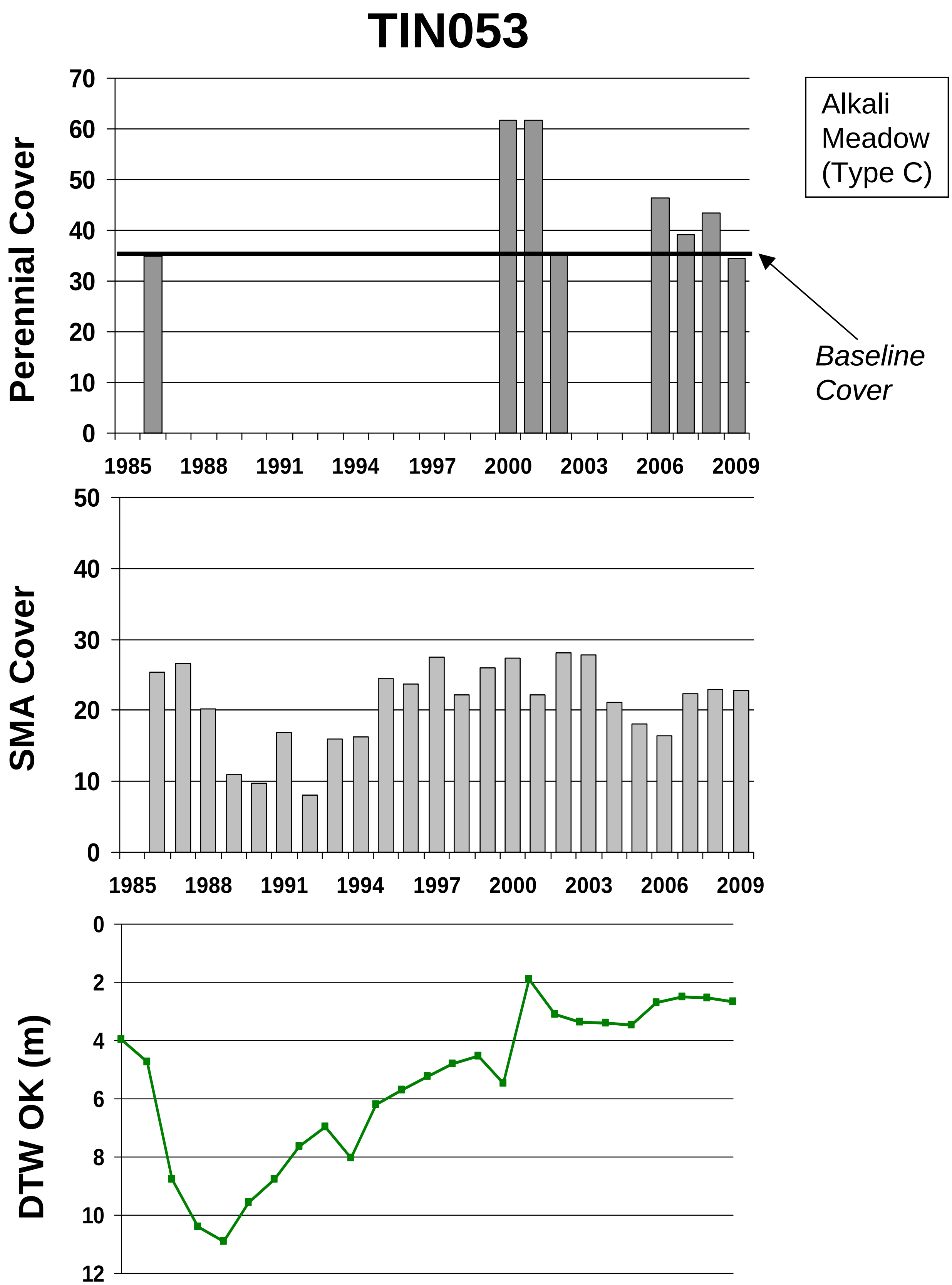

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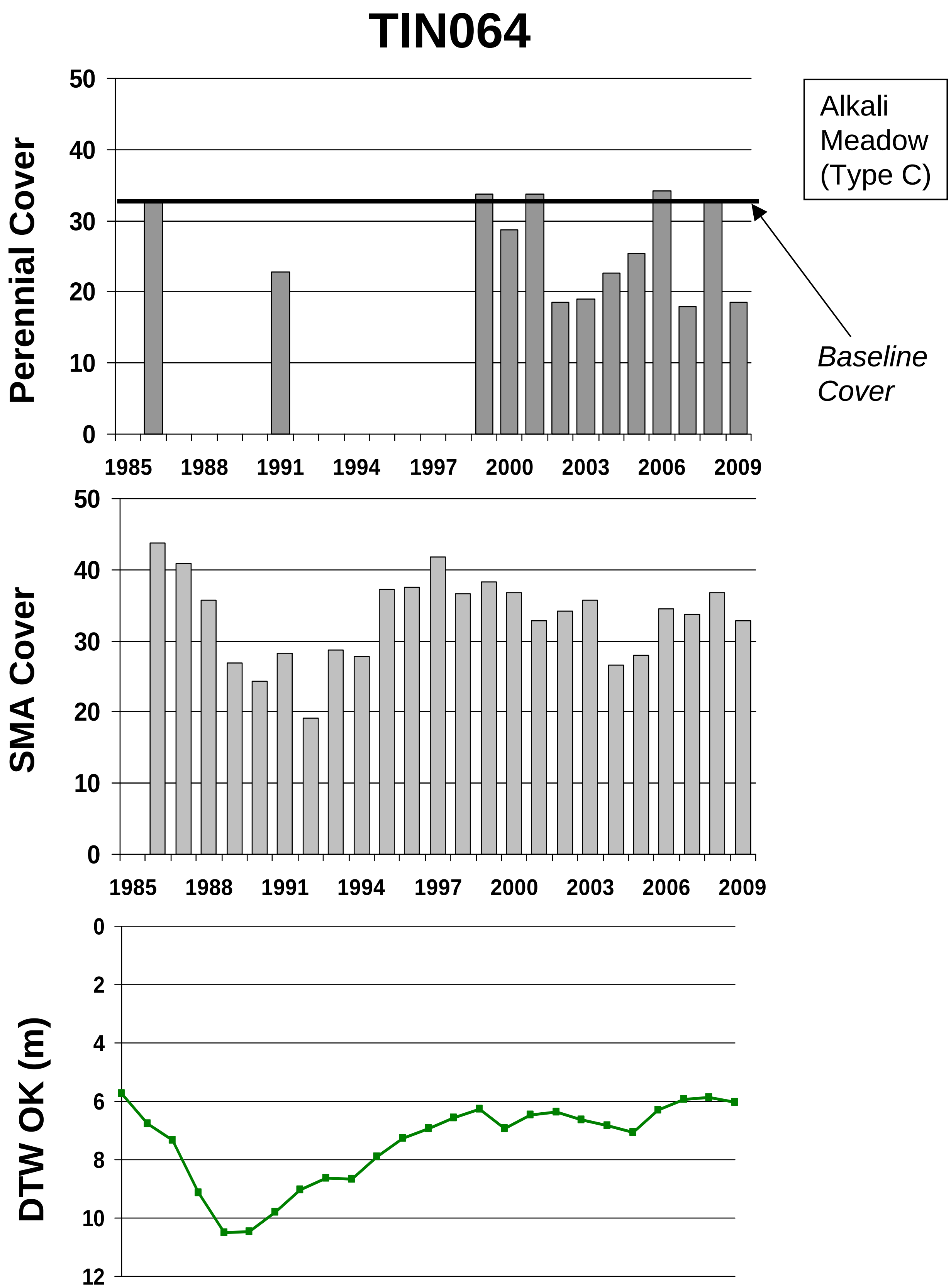

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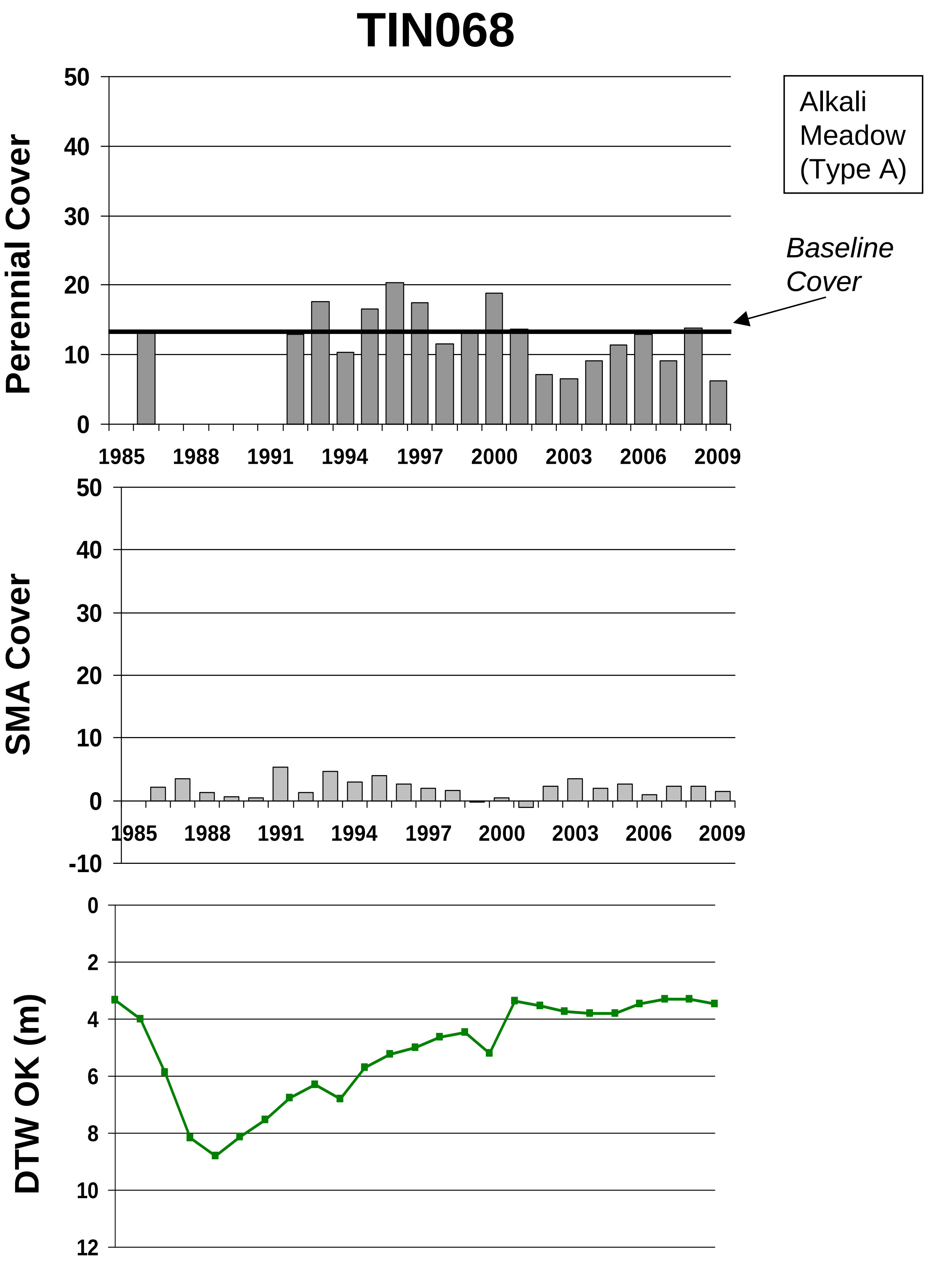

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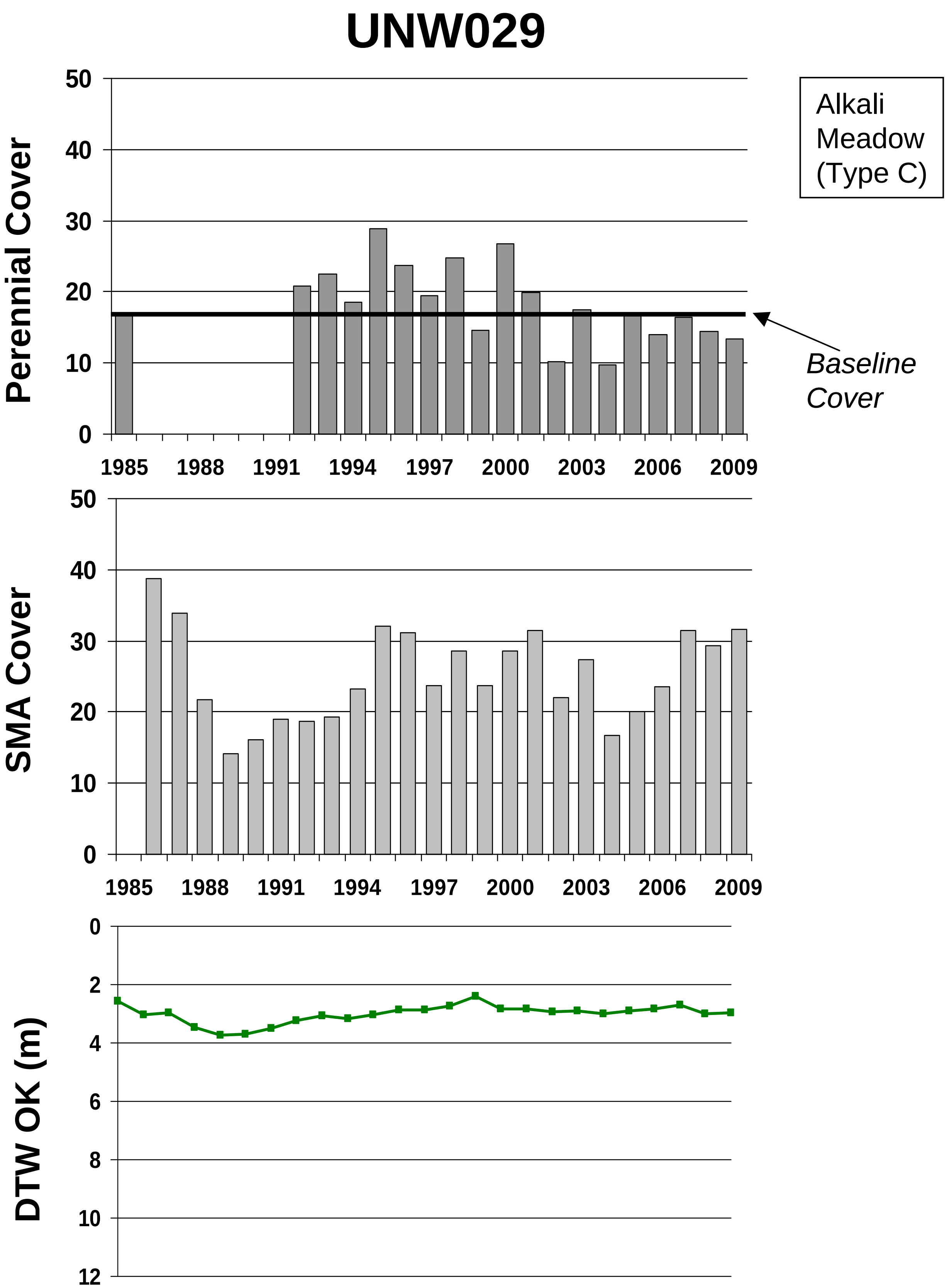

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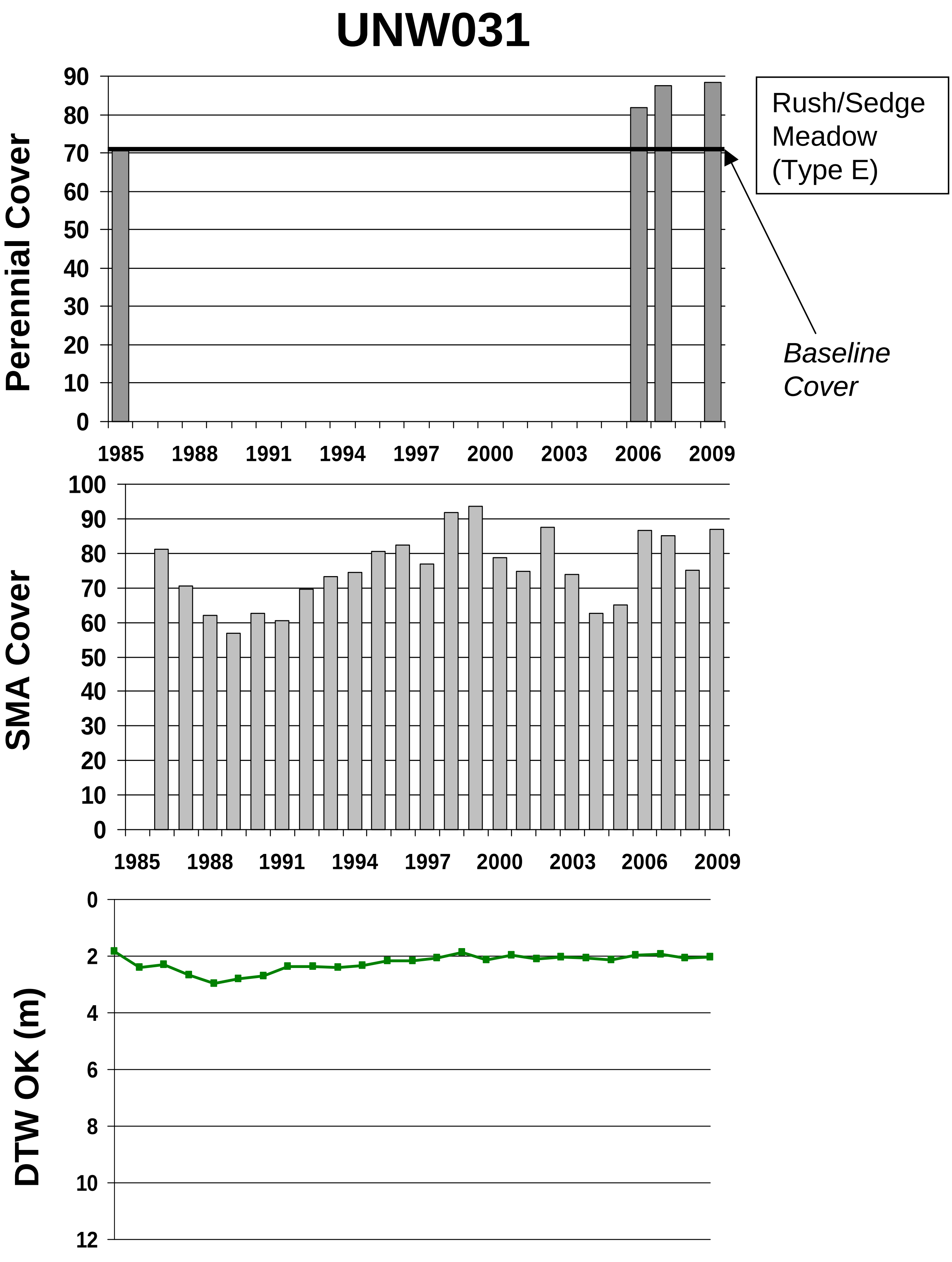

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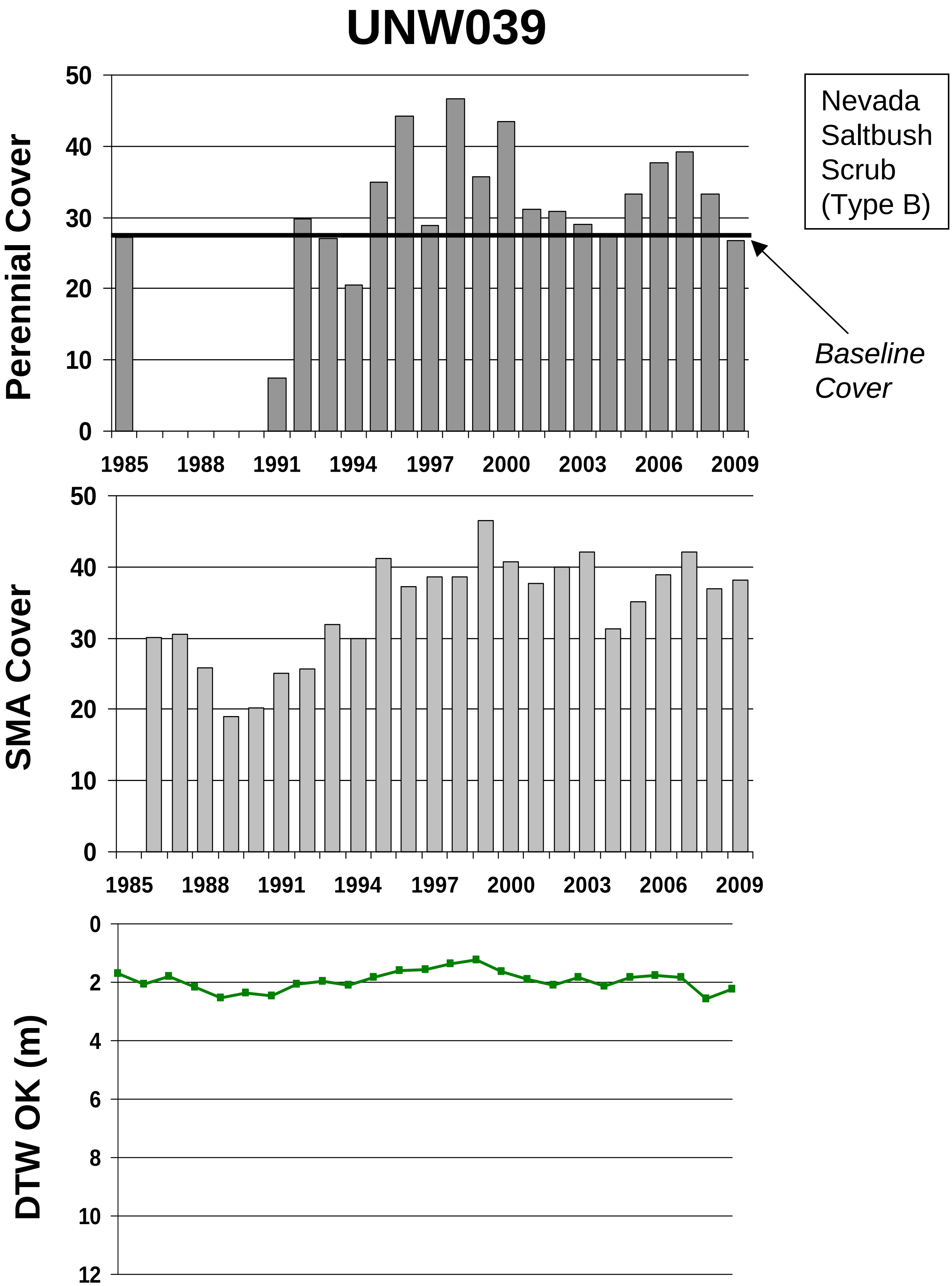

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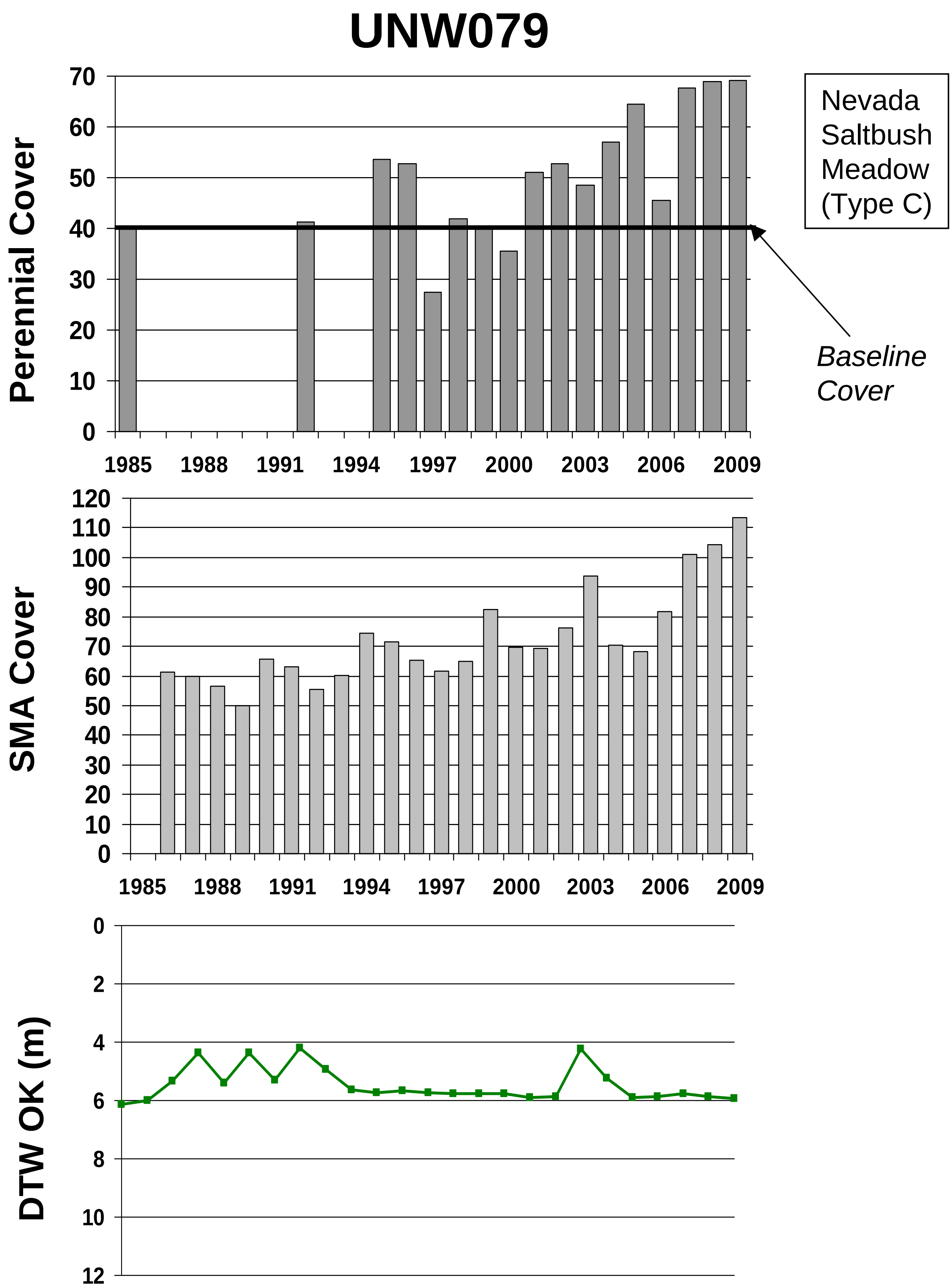

Figure 100. 2009: Control